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GEOLOGICAL AND SEISMOLOGICAL INVESTIGATIONS AT RIRIE DAM, IDAHO

by

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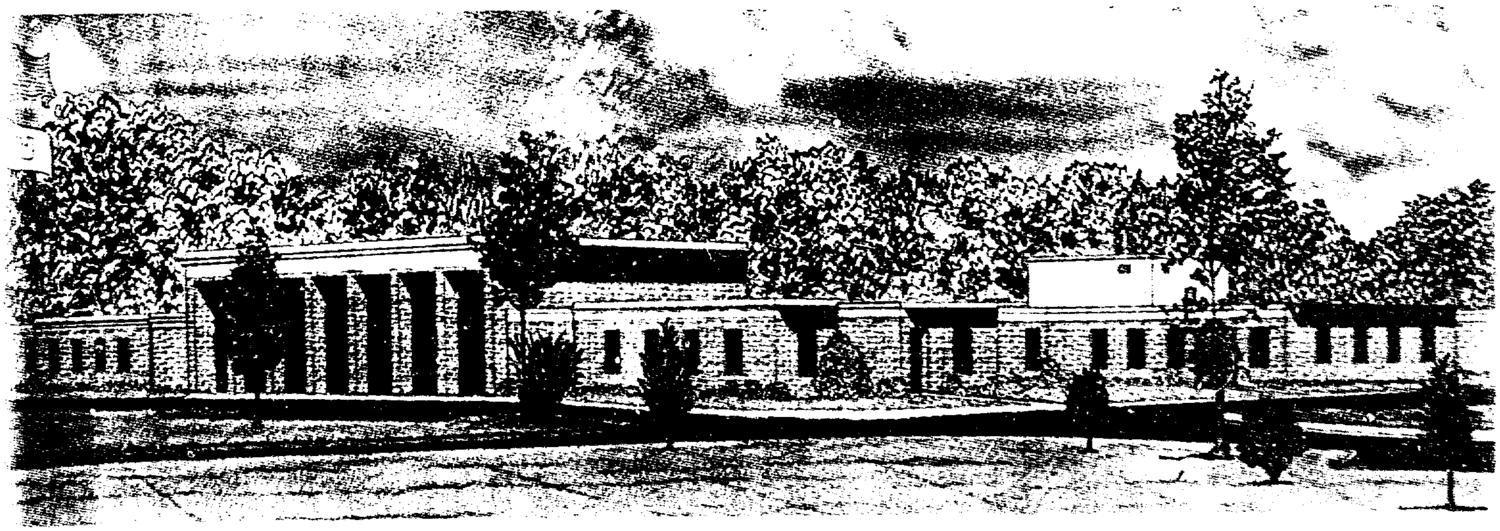

Prepared for U. S. Army Engineer District, Walla Walla
Walla Walla, Wash. 99362

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Geological and seismological studies were conducted at Ririe Dam in southeastern Idaho to identify and define potential seismic hazards at the site and beyond. The geological investigations at the site concentrated on interpreting two significant displacements in basalt flows in the embankment foundation, which formerly had been classed as faults. Core drilling was conducted at the downstream toe of the dam to gather additional data. Core drill data plus data obtained from field observations were integrated with data from previous

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20. ABSTRACT (Continued)

exploration programs and evaluated using structural contour and isopach techniques. These evaluations resulted in the conclusion that the offsets in the basalts were due, in one case, to a landslide and, in the other, to topography; no active or capable faults are present under the dam or in the immediate vicinity.

Faulting and historic seismicity were investigated within a radius of approximately 200 km of the site. Aerial photography, LANDSAT imagery, and aerial overflights were a part of the regional fault studies. The regional fault studies indicated that active or capable faults were present in the Yellowstone National Park (YNP) area. Nearby faults, such as the Grand Valley and Snake River faults east of the site, were not considered to be active or capable. The level of seismic velocity at the site and on the nearby Snake River Plain (SRP) is low. However, high levels of seismicity occur in the YNP area and along the Utah-Idaho border and intermediate levels occur in the Caribou Range south of the site and to the west of Palisades Reservoir. Palisades Reservoir has been cited as having induced earthquakes in the Caribou Range. There is no compelling evidence for this, nor at the Ririe Dam.

On the basis of seismicity and tectonics, three seismic zones--A, B, and C--were identified. Zone A was the YNP area approximately 105 km from the site. The maximum earthquake (ME) in this zone is a magnitude 7.5 event which would produce the following peak ground motions at the site: acceleration, 0.22 g; velocity, 32 cm/sec; displacement, 20 cm. Zone B included the seismically active area along the Utah-Idaho border and within approximately 40 km south of the site. The ME in this zone is a magnitude 7.0 event occurring at a distance of 40 km (far field) from the site; the peak ground motions are: acceleration, 0.28 g; velocity 40 cm/sec; and displacement, 23 cm. Zone C included SRP, the site, and areas between Zones A and B. The ME in this zone is a magnitude 5.5 event occurring 15 km (far field) from the site; the peak ground motions are: acceleration, 0.16 g; velocity, 25 cm/sec; and displacement 15 cm. For all zones, the bracketed durations (acceleration $\geq$ 0.05 g) would be 10 sec for hard rock under the site. The design basis earthquake ground motions are those from Zone B, and the operating basis earthquake ground motions are those from Zone C.

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PREFACE

This study was conducted by the U. S. Army Engineer Waterways Experiment Station (WES) and was authorized by the U. S. Army Engineer District, Walla Walla, 16 February 1978, by appropriation order No. E86-78-0044, and the Office, Chief of Engineers, U. S. Army.

The work was accomplished and the report written by Dr. David M. Patrick, Engineering Geology and Rock Mechanics Division (EG&RMD), Geotechnical Laboratory (GL), with assistance from Mr. Charlie B. Whitten, EG&RMD. Dr. Ellis L. Krinitzsky, EG&RMD, provided general technical supervision. General supervision was also provided by Dr. Don C. Banks, Chief, EG&RMD, and Mr. James P. Sale, (retired) Chief, GL.

Consultants on this project were Messrs. David J. Leeds, Los Angeles, Calif., and Burton H. Marliave, Walnut Creek, Calif. The authors acknowledge the assistance of Messrs. Fred J. Miklancic, Chief, and William L. Sanguine, Geology Section, Walla Walla District; Professor David B. Slemmons, McKay School of Mines, University of Nevada at Reno; and Dr. William F. Marcuson III, GL, WES.

COL John L. Cannon, CE, and COL Nelson P. Conover, CE, were Commanders and Directors of WES during the conduct of this study and preparation of this report. Mr. Fred R. Brown was Technical Director of WES.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acre-feet	1233.489	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
inches	25.4	millimetres
miles (U. S. statute)	1.609347	kilometres
square miles	2.589998	square kilometres

GEOLOGICAL AND SEISMOLOGICAL INVESTIGATIONS AT RIRIE DAM, IDAHO

PART I: INTRODUCTION

Purpose and Scope

1. The purpose of this study was to investigate and evaluate the potential earthquake ground motions at Ririe Dam located in southeastern Idaho. This study was conducted in compliance with ER 1110-2-1806 (Office, Chief of Engineers, 1977).

2. The study included both geological and seismological investigations and consisted of the following elements: (a) an evaluation of the local and regional geology with respect to active or capable faults, (b) a review of historical regional seismicity, and (c) the determination of the maximum earthquake that will affect the site as well as the attenuated peak ground motions at the site.

General Description of Ririe Dam and Lake

3. Ririe Lake is located on Willow Creek, a tributary of the Snake River in Bonneville County, Idaho (Figure 1). The dam is approximately 15 km northeast of Idaho Falls. The dam embankment is a zoned earth- and rock-fill structure 251 ft* high, 840 ft long, and 40 ft wide at the crest. The lake at maximum pool (elevation 5119 ft) has a storage capacity of approximately 100,000 acre-ft. The multipurpose dam and lake serve for flood control, recreation, and irrigation. The dam was designed and constructed by the U. S. Army Engineer District, Walla Walla, and then turned over to the U. S. Bureau of Reclamation for operation in 1978. Filling of the reservoir began in 1976.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 5.

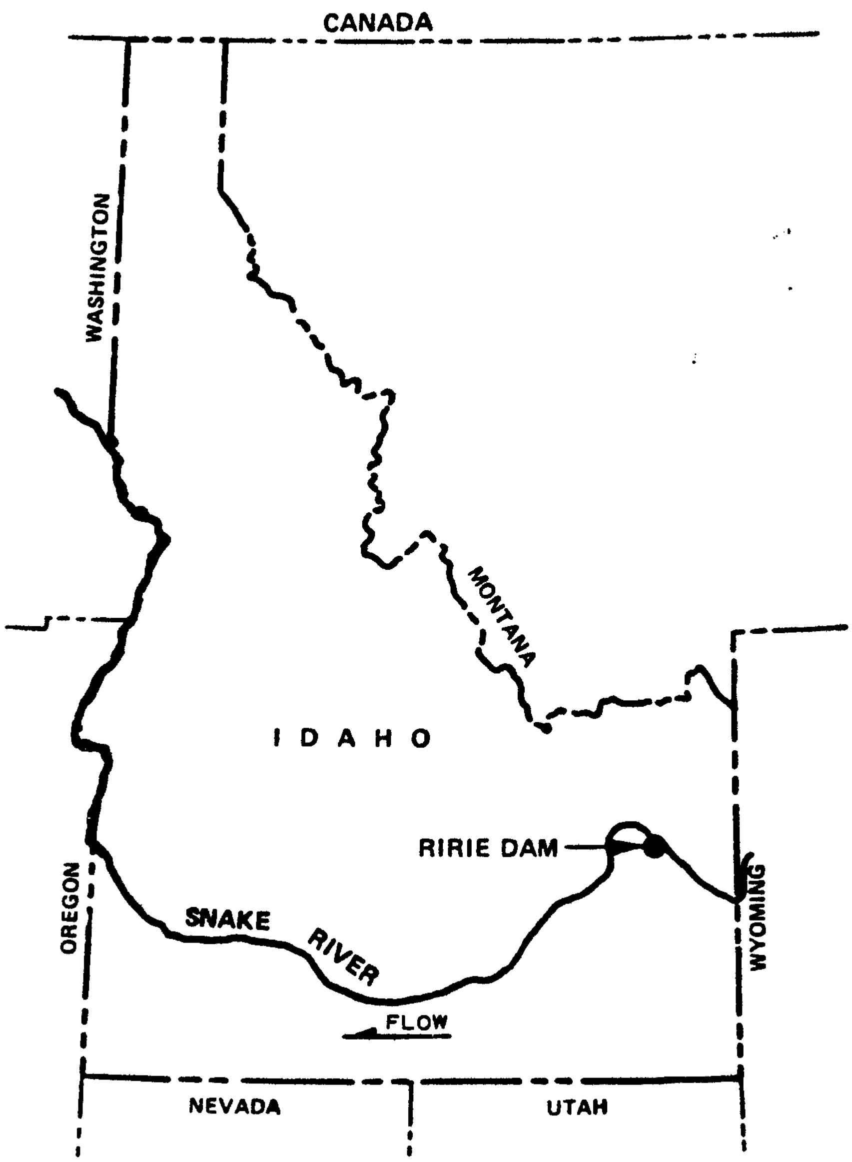


Figure 1. Ririe Dam and vicinity

PART II: GEOLOGY

Physiography and Drainage

4. The Ririe Dam site is situated in the southeastern portion of the Snake River Plain section of the Columbia Plateau Physiographic Province. This location is 10 km north of Middle Rocky Mountains Province, 100 km south of the Northern Rocky Mountains Province, and 10 km north of the Basin and Range Province. The portion of the Snake River Plain containing the site is elevated above the alluvial plain of the Snake River and forms the southern part of the Rexburg Bench. The alluvial plain of the Snake River exhibits low relief, but the topography of the dam and reservoir areas on the Rexburg Bench is hilly, exhibits approximately 1150 ft of relief at the damsite, and is considerably higher in the upstream portions of the Willow Creek basin. Generally, the relief on the Rexburg Bench increases from north to south. The site is also located to the west of the Snake River and Teton Ranges and approximately 80 km southwest of Yellowstone National Park.

5. The dam is located on Willow Creek approximately 24 km upstream of the confluence of Willow Creek and the Snake River. The Snake River heads in northwestern Wyoming and flows southwesterly to enter Idaho in its southeast corner, then flows northwest through the Palisades Dam and Reservoir. The Snake River flows then across the Rexburg Bench in the vicinity of Poplar, Idaho, continues northwest to Menan Buttes, and finally flows to the southwest toward Idaho Falls. Three kilometers downstream from the dam, Willow Creek emerges from the Rexburg Bench onto the Snake River alluvial plain, upon which it meanders for 21 km before it flows into the Snake River.

Stratigraphy

6. The geology of the dam and reservoir areas is dominated by volcanic rocks. Figure 2 shows the areal geology, and Figure 3 presents a generalized stratigraphic section of the rocks in the vicinity of the dam and reservoir. Figure 4 is a location map and Figures 5 through 10

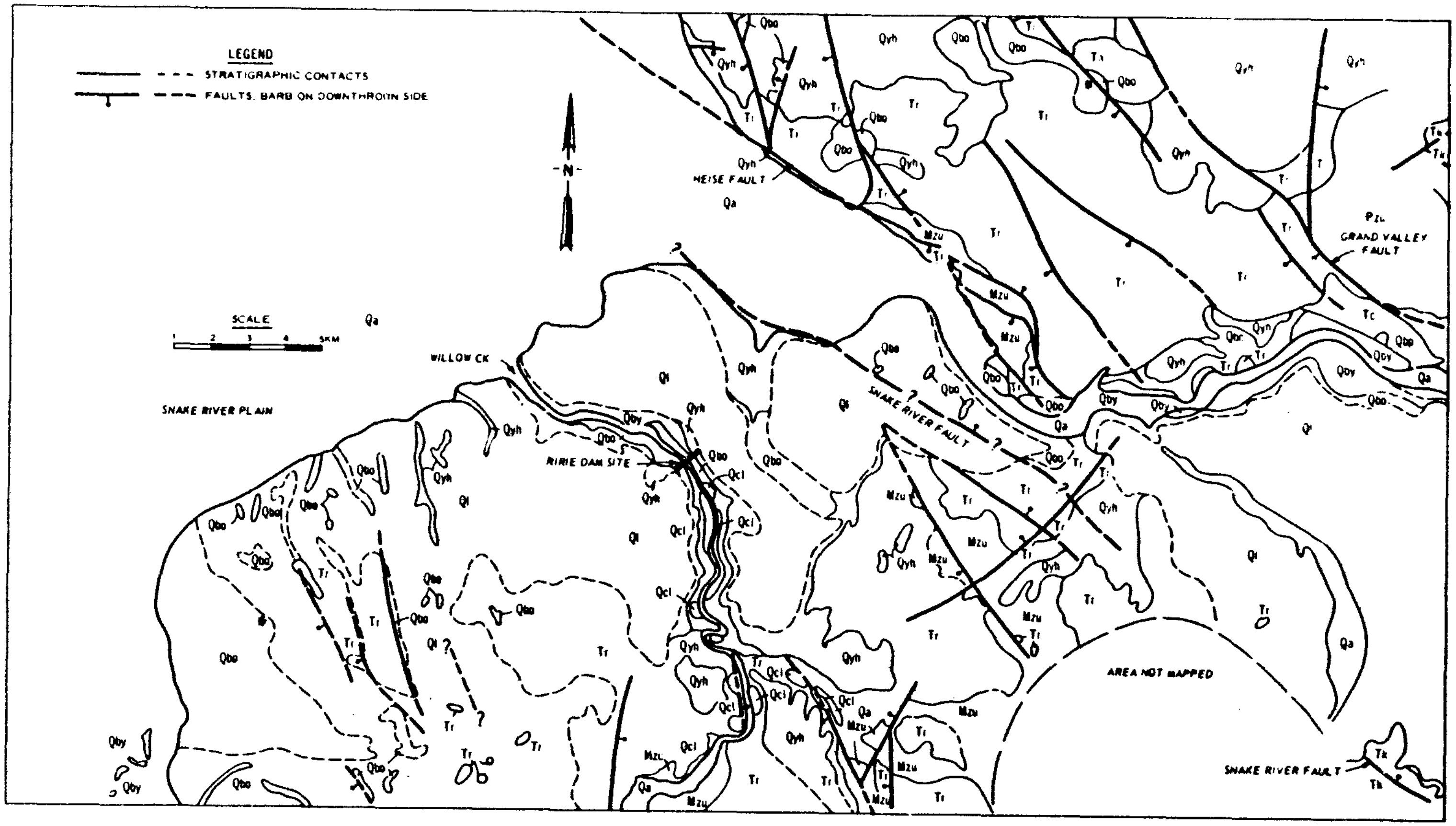


Figure 2. Areal geology in the vicinity of Ririe, Idaho (see Figure 3 for definition of symbols)

MAP SYMBOL*	POTASSIUM/ ARGON DATING (MILLION YEARS)	GEOLOGIC AGE	MARKER HORIZON NUMBER	LITHOLOGY		DESCRIPTION	THICKNESS IN FEET MIN	MAX	AVG
C	–	QUATERNARY (PLEISTOCENE)			LOESS	Tan, fine-grained, wind-blown silt. Occurs on upland areas.		~3	
Qbv	3.1 ± 0.2	TERTIARY (PLIOCENE)			INTRACANYON FLOW	Characterized by large (average length 0.4 inches) tabular feldspar crystals. The rock is blue gray to black in color and vesicular in texture. It is generally columnar in structure and is only evident on the right abutment above 5020 elevation where it forms cliffs. This flow makes contact with materials forming the older erosional surface. As such, it overlies both channel gravels and volcanic flows, and the contact could include other alluvial materials.	15	128	72
Qrh	3.2 ± 0.2				RHYOLITE	Fine grained with needle shaped crystals. It is soft to moderately hard and its color varies from pink to gray. A thin layer of ash is often found at the base of the rhyolite. This material can rest on the basalt flows or the channel gravel.	6	65	30
–	–				CHANNEL GRAVELS	Confined to a buried channel exposed along the right abutment during the stripping contract. They extend an unknown distance into the hillside. The deposit consists of lenticular and intertongued clays, silts, sands, and gravels. The exposed channel extends from DH-13 through DH-24.	34	48	43
Qbs	8.7 ± 0.7				BASALT (FIRST FLOW BASALT)	Flow is a marker bed because of the unusual arrangement of the feldspar crystals. These crystals are 0.2 to 0.3 inches in length and are arranged in clusters or rosettes. The rock is vesicular and gray in color	9	56	31
	–		12		BASALT	Hard, fine grained with vesicles ranging in size from 0.5 inches to "pin hole". It is dark gray in color	12	83	71
			13, 13a		CONTACT BRECCIA	The clay is gray-green to gray and is very plastic. It contains thin lenses of silts and sands. There is a 2 foot contact breccia zone capping the clay bed. The breccia is orange to brown in color and has inclusions of basalt fragments.	1	7	2
					CLAY		2	38	24
			14		BASALT	Hard, medium grained, slightly vesicular and dark gray in color. Feldspar crystals appear as white lathes in the rock.		78	50
			15, 15a		CONTACT BRECCIA	This clay is generally gray-green to yellow-green and is plastic. It is capped by a contact breccia zone.	2	11	7
					CLAY		1	23	9
			16		BASALT	Hard, fine grained, slightly vesicular and dark gray in color.	13	41	30
			17, 17a		FLOW BRECCIA	The basalt is similar to flow 16 - 17 except that it is capped by a flow breccia zone.	2	15	9
	7.3 + 0.4	?			BASALT		8	52	18
Tr	–		18		BASAL SEDIMENTS	Considered to be part of the Salt Lake Formation. They are clay and silty clays, soft to moderately hard and are red brown to tan in color. Beds of the Salt Lake Formation are exposed in the canyon wall several miles upstream from the damsite.	UNDETERMINED DEPTH (ESTIMATED AT 1000'S OF FEET)		

* SYMBOLS ON GEOLOGIC MAP (FIGURE 2) AFTER USGS.
OTHER SYMBOLS SHOWN ON GEOLOGIC MAP BUT NOT SHOWN HERE ARE:
Qa - ALLUVIUM; Qd - LANDSLIDE MATERIAL, Mz - UNDIFFERENTIATED MESOZOIC SEDIMENTS

Figure 3. Stratigraphic column - Ririe Dam site

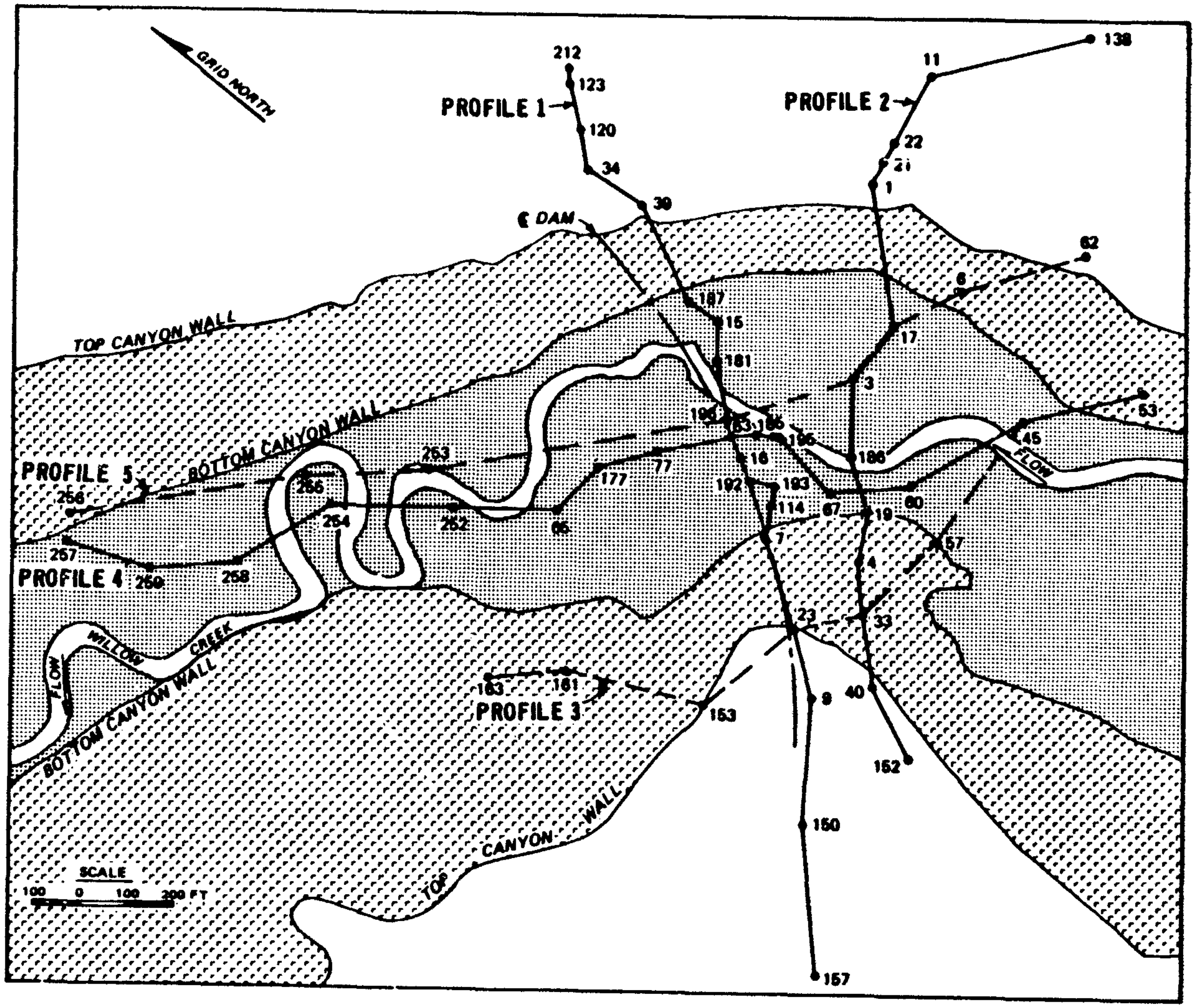


Figure 4. Location of geologic profiles

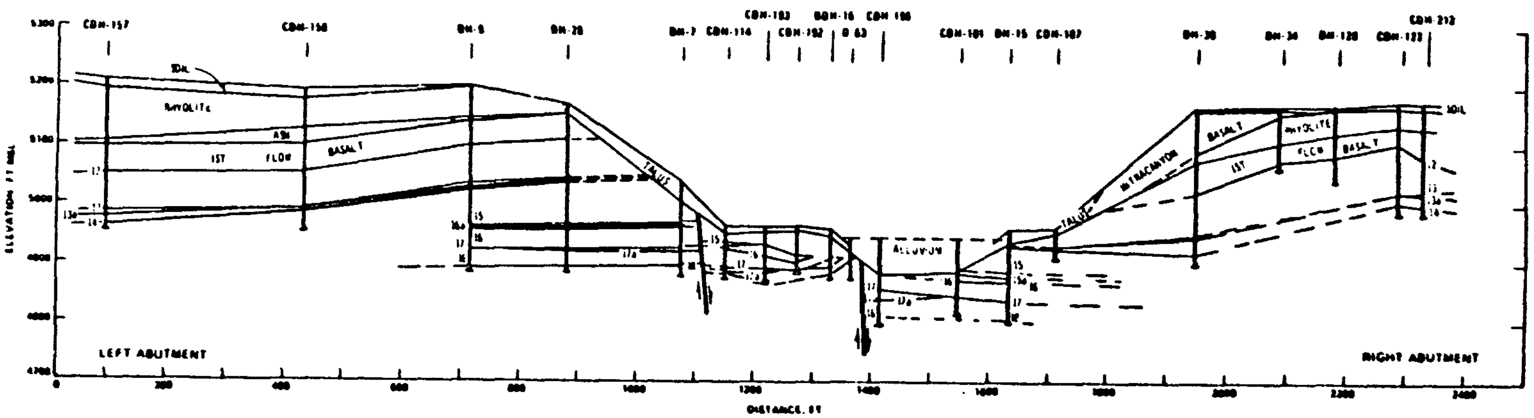


Figure 5. Geologic profile 1 of the volcanic units

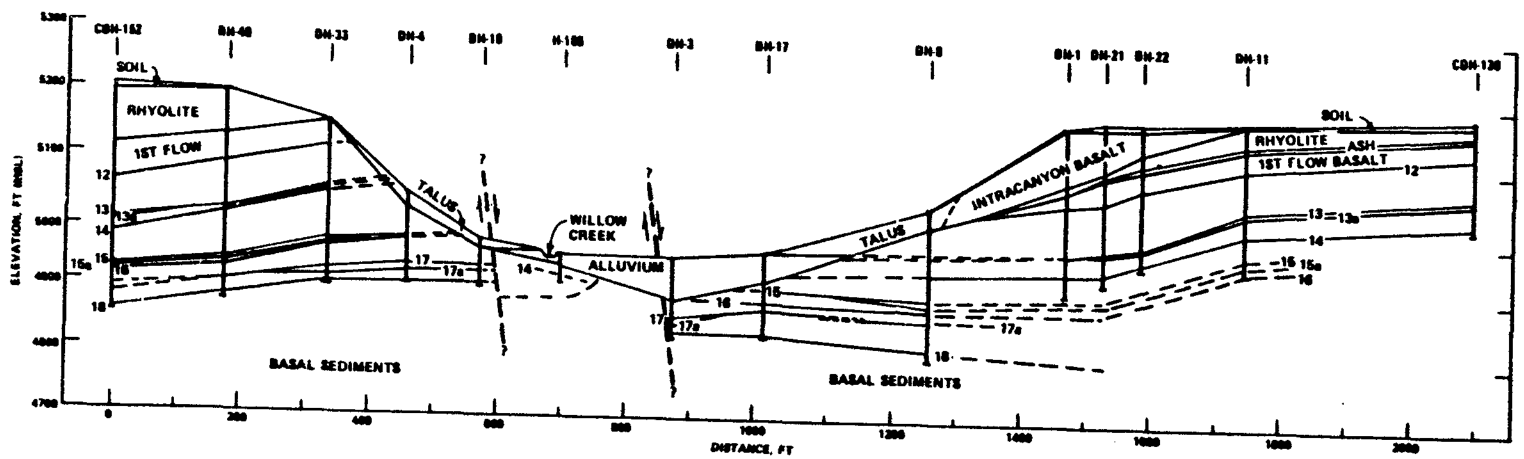


Figure 6. Geologic profile 2 of the volcanic units

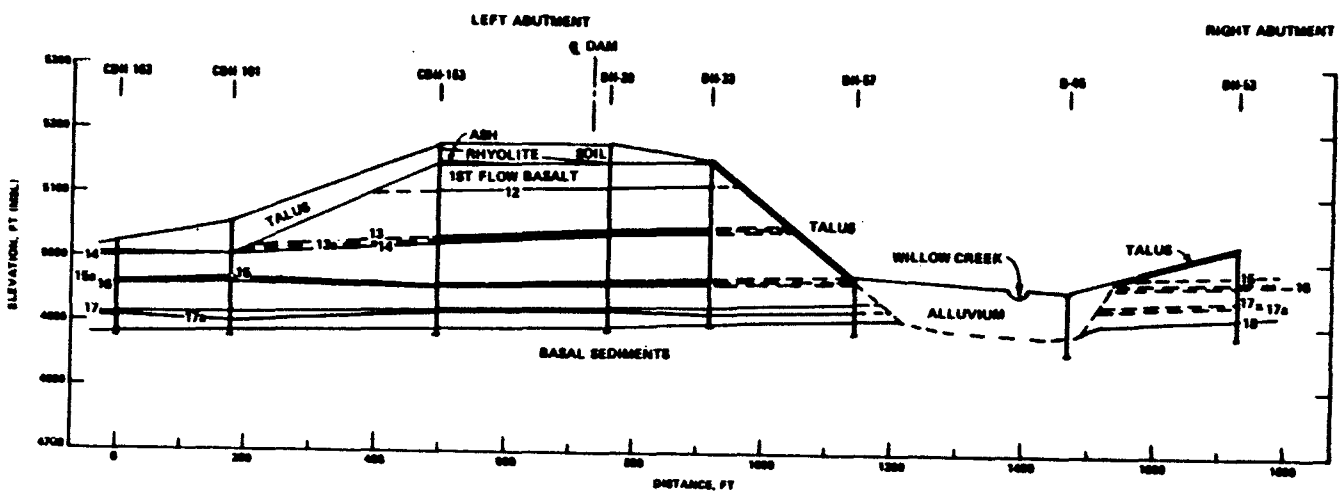


Figure 7. Geologic profile 3 of the volcanic units

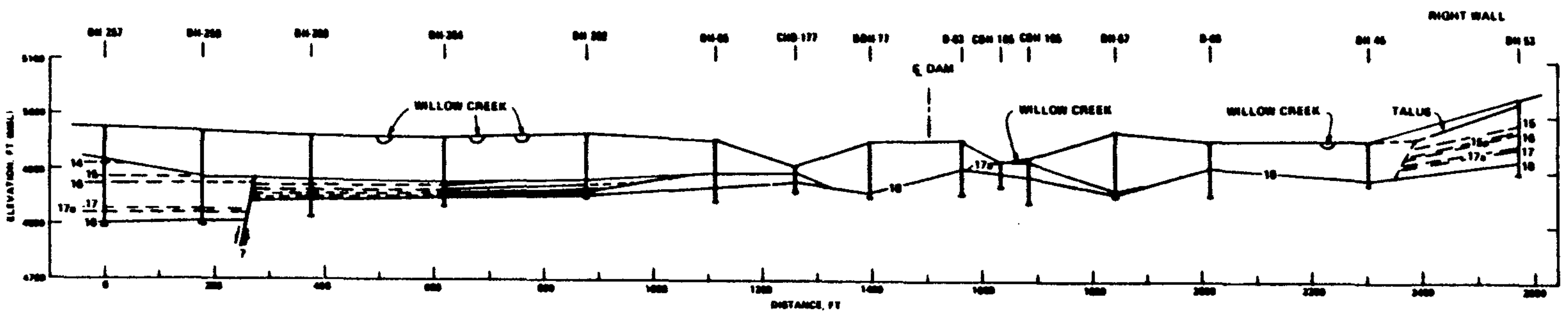


Figure 8. Geologic profile 4 of the volcanic units (see Figure 9 for comparison)

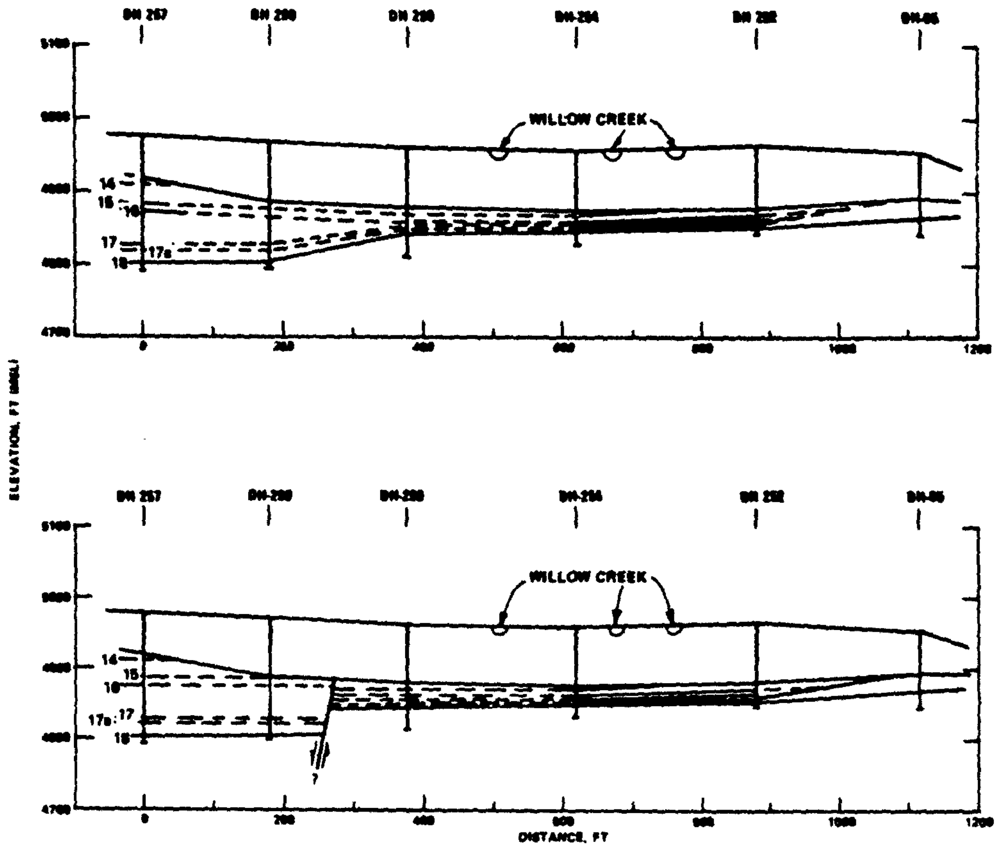


Figure 9. Geologic cross section along profile 4 showing two interpretations of larger fault area (Upper cross section shows the offset to be a topographic feature and the lower cross section shows a fault interpretation.)

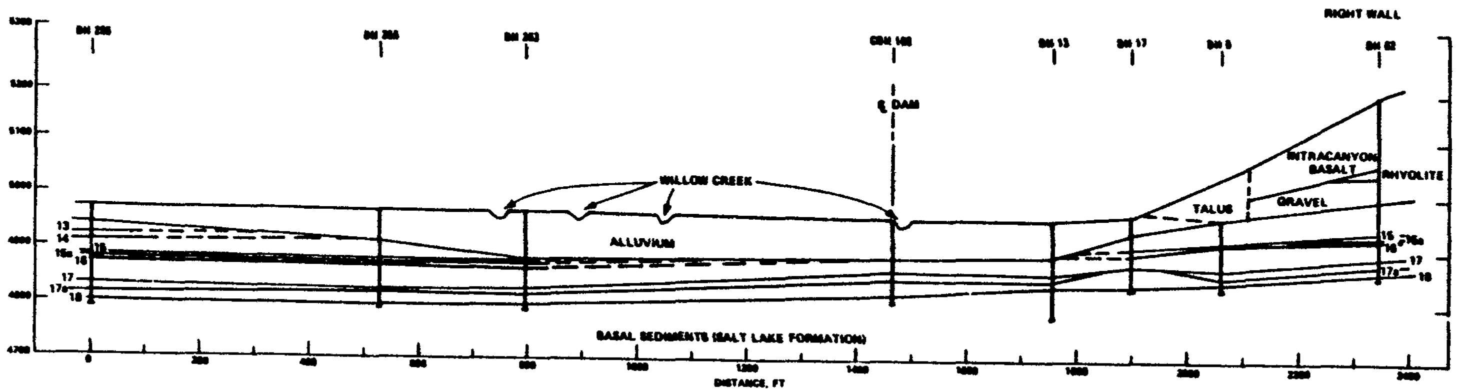


Figure 10. Geologic profile 5 of the volcanic units

are geologic profiles of the volcanic units. There are five distinct major lithologic and stratigraphic units exposed (U. S. Engineer District, Walla Walla, 1977). These units are, from oldest to youngest, respectively:

a. A thick sequence of ash, rhyolite and sediments of Late Tertiary age which are called "basal sediments" or Salt Lake formation.

b. A sequence of basalt of Quaternary or Tertiary age.

c. Channel gravel deposit.

d. A rhyolite flow.

e. A basalt flow (Intracanyon Flow).

7. The upland areas are mantled by several feet of windblown silt (loess) of Quaternary age and the alluvium of Willow Creek converts Pleistocene to Holocene age silts, clays, sands, and gravels. Generally, the knowledge of the local geology is based upon the U. S. Geological Survey (USGS) open file geologic map by Prostka and Hackman (1974), boring logs and cross sections prepared by the Walla Walla District, CE, and geological studies conducted as a part of this investigation. These recent studies consisted of a reevaluation of existing geological information derived from the original exploration program, field examination of exposed rock units, radiometric dating of selected flows, and additional rock drilling. The geological units are described in the next sections.

Basal sediments

8. This unit is termed "basal sediments" in the foundation reports and is presumed to be approximately equivalent to the Salt Lake formation. This material is mapped as "Tr" on Prostka and Hackman's (1974) map and is Pliocene (Tertiary) in age. The unit consists of rhyolitic welded tuffs, lava flows, and nonwelded tuffs. Exposures of this unit in Meadow Creek, an upstream tributary of Willow Creek, consist of volcanic ash beds (nonwelded tuffs), silts, and sands. The surfaces upon which these individual volcanic and nonvolcanic materials were deposited are apparently quite irregular as indicated by steep primary dip. These materials are unweathered as exposed in Meadow Creek, but the basal sediments encountered in boreholes under and near the dam consist of silt and clay that most probably resulted from the devitrification and

weathering of the volcanic glass. This unit is believed to be quite thick, perhaps thousands of feet thick. However, the deepest exploratory penetration of this unit was approximately 100 ft.

Older basalt

9. Unconformably overlying the basal sediments and underlying both the rhyolite flow and the channel gravels are approximately 251 ft of basalt flows. These basalt flows are labeled "Qbo" on Prostka and Hackman's (1974) map and are considered by them to be of the Quaternary age. At the damsite the unit consists of predominant hard, dark gray, fine-grained, vesicular basalt. This sequence of basalts has been lithologically and stratigraphically divided into five individual flows or flow units on the basis of interbedded clays, flow or contact breccias, and lithologic dissimilarity. Ten key marker horizons have been identified and are shown on the stratigraphic column and on the cross sections. Generally these marker horizons can be identified throughout the vicinity of the dam. However, the examination of boring logs revealed that marker horizons 17 and 17A are least continuous. These interbedded clays and associated contact or flow breccia zones apparently indicate surfaces of unconformity upon which successive flows were extruded. Horizon 12 reflects a distinct change in lithology in terms of the appearance of clustered plagioclase phenocrysts, which appear above horizon 12 and not below it. This porphyritic basalt is termed the "first flow basalt." This horizon is not a surface of unconformity.

Channel gravels

10. Exploratory drilling for the emergency spillway in the right abutment revealed the presence of approximately 40 ft of predominant gravel interbedded with sand, silt, and clay. The drilling logs indicated that these gravels, which are presumed to represent a channel deposit, underlie both the rhyolite and the youngest rock unit, the intracanyon basalt. The channel gravels lie unconformably upon the older basalt flows and represent downcutting to at least horizon 14 in the older basalt flows.

Rhyolite flow

11. Unconformably overlying the channel gravels and first flow basalt in the right abutment and only the first flow basalt in the left is a fine-grained, soft to moderately hard, pink to gray, rhyolite flow. This material is the gray rhyolite flow. The base of the flow consists of ash and locally obsidian. This material is the Huckleberry Ridge tuff of Prostka and Hackman (1974) who describe the unit as a rhyolite, welded, ash-flow tuff. These authors give the age of the material as Pleistocene.

Intracanyon flow

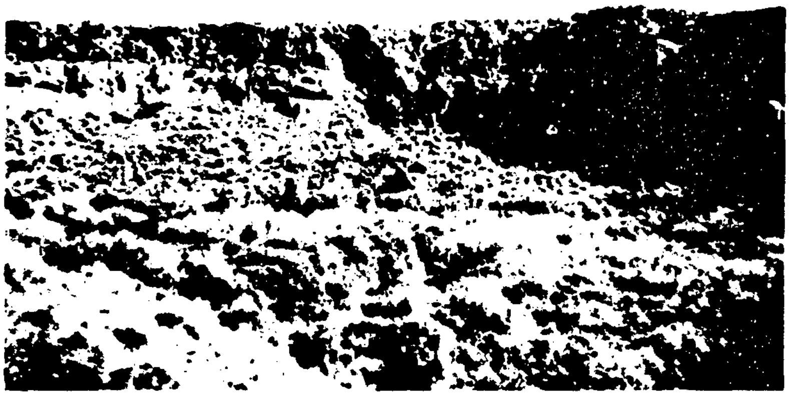
12. Unconformably overlying the local channel gravels and rhyolite is approximately 72 ft of gray to black, porphyritic, and vesicular basalt. This unit exhibits feldspar phenocrysts and columnar jointing and was apparently extruded along a canyon ancestral to the present Willow Creek canyon. The contact between the intracanyon flow and the older basalts along the north side of Willow Creek canyon approximately one mile downstream of the dam is shown in Figure 11.

Loess

13. Overlying the rhyolite flow and generally covering most of the volcanics is several feet of Pleistocene age windblown silt. This loessial material is quite extensive and effectively conceals much of the structural and stratigraphic relationships in the underlying rocks. The correct interpretation of the stratigraphic and structural relationships between these volcanic flows and the interbedded gravels is an important aspect of this study because of the need to identify geologic faults that may be capable of producing earthquakes.

14. The geological interpretation and identification of the structure at Ririe Dam is complicated by the veneer of loess and by the fact that the dam is completed and it and the reservoir cover locations of interest. Furthermore, the very nature of the flows results in additional complications; these result because the flows have been extruded on highly irregular, eroded surfaces.

15. The authors believe that the single most important consideration in the evaluation of the geological data with respect to faulting



a. Distant view

b. Close-up

Figure 11. Unconformable contact between overlying intracanyon basalt (darker rock) and underlying older basalts

is the existence of at least six unconformities within approximately 350 ft of total section.

Geologic Structure

16. Generally, the structural makeup of the southern portion of the Rexburg Bench is not particularly complex. The basalt units that comprise the abutments dip in a southwesterly direction with the degree of dip ranging from 5 to 30 degrees. In the area south of the Snake River Plain, Prostka and Hackman (1974) have mapped 14 faults of which four are presumed faults; no faults have been identified by these authors at the damsite. All of the mapped faults on the southern portion of the bench are normal, and none are shown to cut the rhyolite (Qyh) in the vicinity of the site. Also, in this area only one fault (11 km southwest of the dam) was found to affect or cut the older basalt (Figure 2); this particular fault occurs between the older basalt and the basal sediments (Tr). All other mapped faults are limited to the basal sediments and undifferentiated Mesozoic units.

17. The Snake River valley northeast of the dam may be at least partially bounded by normal faults. The Snake River fault, shown in the southeastern corner of Prostka and Hackman's (1974) geologic map (see Figure 2), is projected to the northwest where over a part of its length it occurs along the south valley wall of the Snake River valley. The southeastern portion of the northern side of Snake River valley, east of the dam, is bounded by the Grand Valley fault. The Heise fault bounds the northwestern portion of the Snake River valley. North and northeast of the Snake River valley the faulting is more extensive and several faults have cut the rhyolite (Qyh).

18. During construction three faults were found at the dam site; two of these faults occur under the dam and are shown on the cross sections in Figures 5 and 6. Both faults appear to be normal; the fault near the left abutment exhibits a vertical displacement of approximately 30 ft and the one near the center of the dam exhibits a vertical displacement of approximately 75 ft. The strike of the larger fault is approximately

N 40° W. The third fault or shear zone occurs under the intake tower and exhibits a strike which is approximately normal to the axis of the valley. Displacement on this feature was seen during construction; the fault is limited to the older basalt and does not extend into the overlying rhyolite. The age of the rhyolite and the fact that the fault or shear zone does not transect the rhyolite indicate that this feature is not an earthquake source. A further discussion of the two faults under the dam will be given in the section dealing with Field Studies and again in PART III: Fault Studies.

Radiometric Age Dating

19. To more accurately determine the potential activity of the presumed faults at the dam, the absolute ages of the foundation rocks had to be known. Therefore, selected samples of core were taken from drill hole No. 9 (left abutment) and drill hole No. 31 (right abutment) for radiometric age dating. The analyses were performed by Teledyne Isotopes and the dating method was potassium-argon. The results of the analyses are given below:

Unit	Drill Hole No.	Depth ft	Elevation ft, msl	Age Million Years
Intracanyon basalt	31	27	5140	3.1 ± 0.2
Rhyolite	31	31	5136	3.2 ± 0.2
First flow basalt	31	75	5092	6.7 ± 0.7
Basalt, units 17-18	9	304	4893	7.3 ± 0.4

20. It is apparent that the geologic ages of these flows are not Pleistocene (Quaternary), but Pliocene (Tertiary). Also, the ages indicate a hiatus of approximately 3.5 million years between the extrusion of the first flow basalt and the extrusion of the rhyolite--a period of time during which well developed drainage systems could be established. The channel gravels are apparently remnants of this system.

21. Since these rocks are of an older age than the Pleistocene, the determination that a given fault, although displacing a lower flow,

did not displace an upper one would demonstrate no movement on the fault in the last 3 million years and that would essentially require that the given fault be considered not capable. Therefore, the fault or shear zone under the intake tower is noncapable and nonactive.

Field Studies

22. Field studies were conducted to reexamine the geology of the project to determine whether the suspected faults under the dam could be traced beyond the dam. The downstream projection of the local strike (N 40° W) of the larger fault indicated that this fault should head into the right abutment canyon wall a short distance downstream of the dam. Examination of outcrops on the tops, sides, and bottoms of the canyon walls downstream of the dam revealed no evidence of faulting.

23. Outcrops were also examined on the canyon tops and sides upstream of the dam. These observations also revealed no faults; however, there was evidence of landslides or slumping particularly on the left canyon wall.

24. Field examination of outcrops and mapped faults upstream of the dam in the Meadow Creek area generally confirmed the geologic mapping of Prostka and Hackman (1974); that is, there was no evidence for faulting in the older basalt (Qbo) or in the rhyolite (Qyh).

25. The Meadow Creek area is particularly significant for observing the relations between the basal sediments (Tr), older basalt (Qbo), and the rhyolite (Qyh). An enlargement of Prostka and Hackman's (1974) geologic map is shown in Figure 12. From this map it may be seen that the older basalt flows (Qbo) rest unconformably upon the basal sediments (Tr) and that the rhyolite (Qyh) lies unconformably upon both the older basalt flows and the basal sediments. No faulting is indicated.

26. Figure 13 is a cross section taken approximately parallel to Meadow Creek. Figure 14 presents photographs of this area. The dip on the basal sediment surface is evident. This is an apparent dip of approximately 26 degrees. The true dip could be considerably higher.

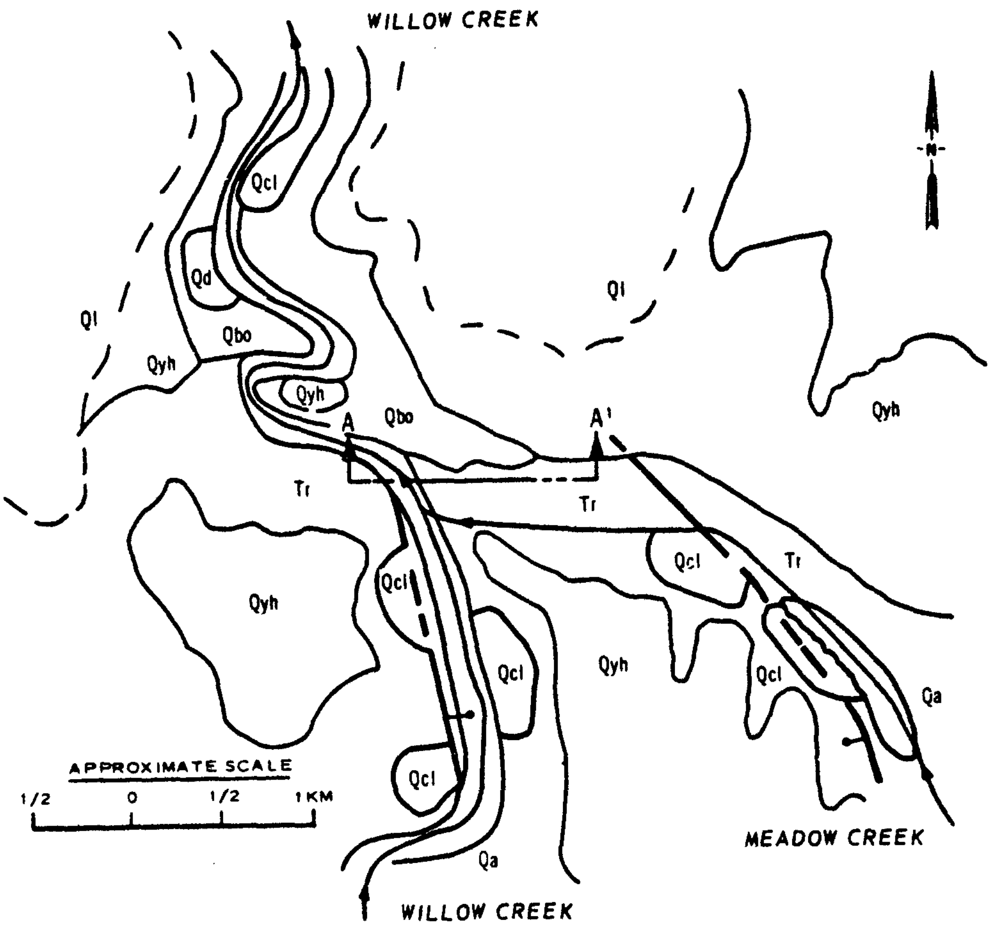


Figure 12. Geologic map of Meadow Creek area (Symbols are defined in Figure 3)

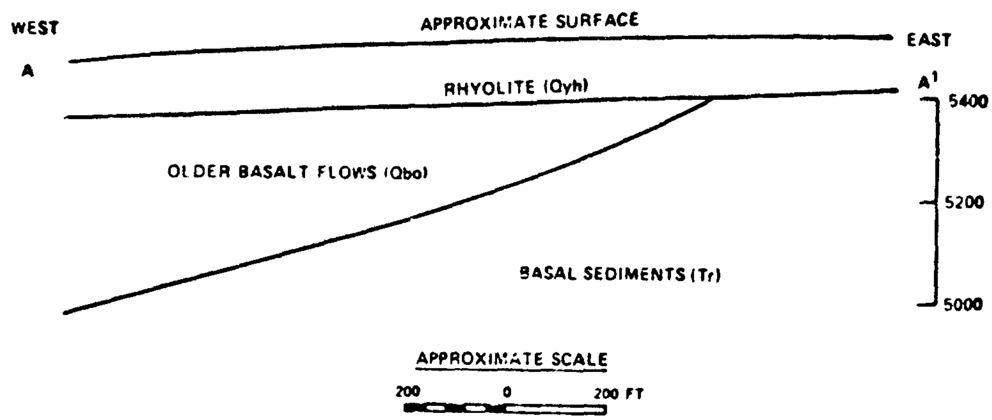
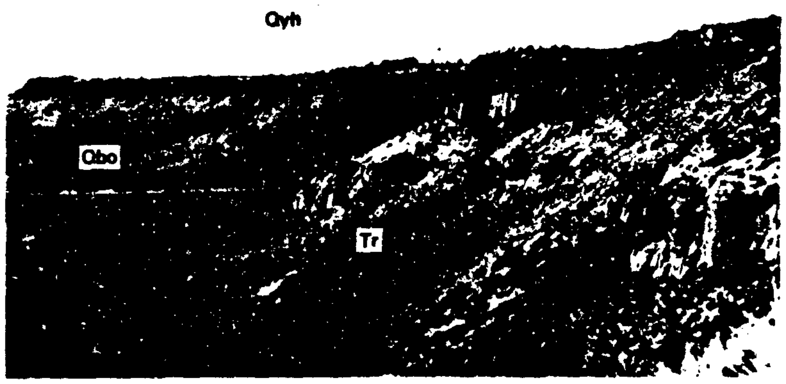
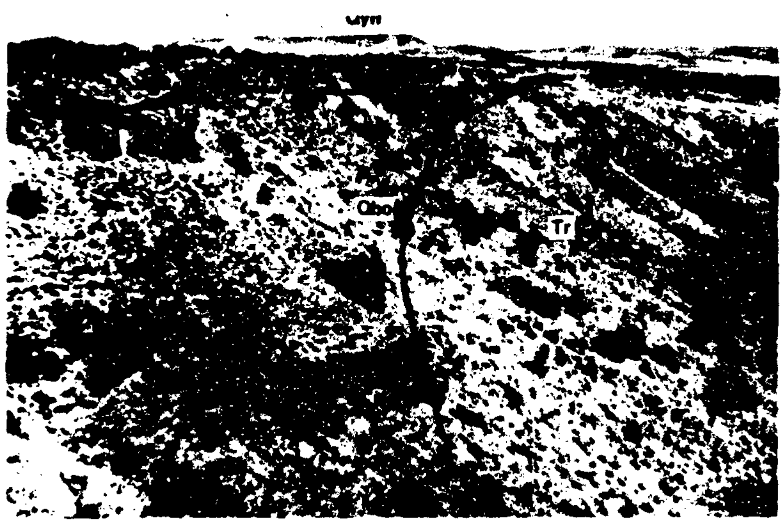


Figure 13. Generalized geologic cross section along Meadow Creek



a. Downstream view



b. Upstream view

Figure 14. Photographs of Meadow Creek valley

Apparently considerable relief had developed upon the basal sediments prior to extrusion of the older basalt. Note that the slope on the surface upon which the rhyolite lies is considerably smaller.

PART III: FAULT STUDIES

General

27. This part of the report describes the activities conducted and information collected to determine whether active or capable faults are present at or in the vicinity of the damsite. Active and capable faults are faults that may generate earthquakes. Active faults are those faults that show evidence of geologically recent movement. Faults that displace Holocene alluvium, for example, would be classed as "active." Capable faults exhibit one or more of the following features (Office, Chief of Engineers, 1977):

- a. Movement at or near the ground surface at least once within the last 35,000 yr.
- b. Macroseismicity instrumentally determined with records of sufficient precision to demonstrate a direct relationship with the fault.
- c. A structural relationship to a capable fault such that movement on one could be reasonably expected to cause movement on the other.

28. The determination that a given fault is active or capable would require that the fault be considered an earthquake source. The size of the earthquake assigned to the fault would be a function of fault length and the regional seismicity. Since three faults have been postulated to occur at or under the dam, it is apparent that whether these three faults are active or capable is of paramount concern.

29. The analyses of the local faults were based upon information presented in various design memoranda for the dam, field examination of the site and environs (given in PART II), data collected during the supplemental drilling program, and examination of LANDSAT and other imagery. The analyses of regional faults involved interpretations of USGS publications, imagery, and aerial overflights.

Imagery Interpretation

30. The examination of large-scale aerial photography and LANDSAT imagery was conducted for the purpose of elucidating the character of local and regional structures (Glass and Slemmons 1978). The results of the examination of aerial photographs of the dam and reservoir area failed to reveal any new data that could contribute to characterizing the presumed local faults at the damsite, and no previously unmapped faults were seen. Specifically, the examination of the along-strike extension of the presumed faults at the dam revealed no trace of faulting. Although preloess faults could be present, there were no indications of loess displacement; however, the loessial upland areas are actively cultivated and this cultivation could easily remove evidence of displacement. Also, there was no evidence of fault displacement along Willow Creek valley; however, the dense vegetation in the valley could easily conceal minor displacements. Figure 15 is an aerial photograph of the damsite taken during site exploration. The damsite is located at the bottom of the photograph. The larger presumed fault under the dam strikes more or less down Willow Creek or possibly into the north canyon walls. No evidence of the fault can be seen. Note, however, the landslide debris on the left (southern) canyon wall downstream of the site. Figure 16 shows the adjacent frame to the south of Figure 15, consisting of the damsite and upstream portions of Willow Creek. Again no upstream evidence for faulting is evident, although landslides are apparent.

31. Two seemingly anomalous features were detected on the aerial photographs. The first is located 19 km upstream of the dam and is shown in Figure 17. This feature is a northeast trending linear topographic ridge shown in the upper left quadrant of the photo. Field examination of the feature revealed approximately 20 ft of relief with a steep slope on the northwest side. Examination of the walls of Willow Creek on strike with the feature revealed no evidence of offset in the outcrop. Other similar but more curvilinear features were found on other photos and in the field. None of these is believed to be a fault. These topographic anomalies are believed to be edges or ends of lava flows.

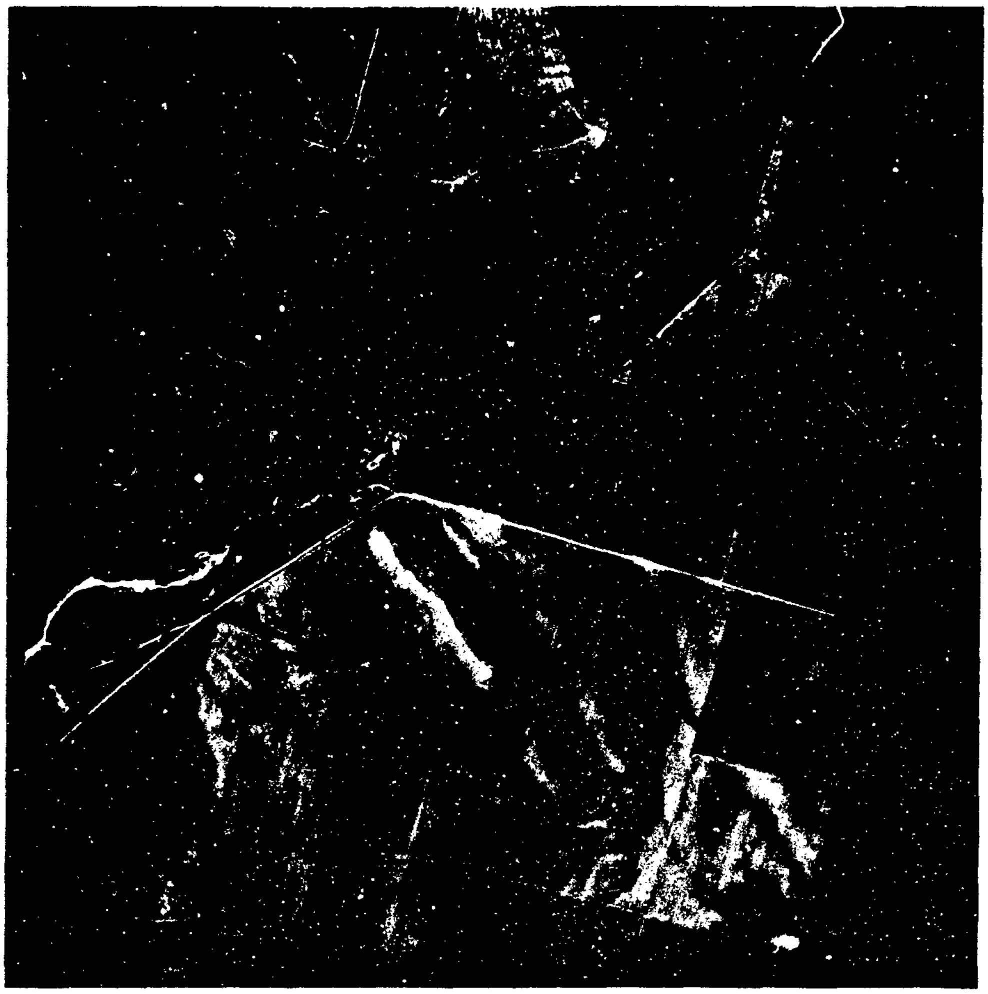


Figure 15. Aerial photography of the damsite during site exploration

Figure 16. Aerial photography of the damsite during site exploration (adjacent frame to the south of Figure 15 photograph)

Figure 17. Anomalous features on aerial photographs

32. The second apparent anomaly occurs approximately 4 km northeast of the damsite where Birch Creek enters the Snake River Plain. This feature, shown in Figure 18, is the rather straight, steep escarpment separating the Rexburg Bench to the southwest from the Snake River Plain to the northeast. The escarpment is the southeastern boundary of the Snake River graben and is aligned with and apparently conforms to the most northwesterly extension of the Snake River fault shown in Figure 2. The escarpment is considered to be concealed by alluvium or loess throughout most of its length. In the field the escarpment appeared as a typical valley wall adjoining an alluvial valley. There was no evidence that the offset represented recent tectonic displacement. Furthermore, the photos and field evidence show that Birch Creek valley completely truncates the escarpment indicating that this boundary fault predates the alluvial filling of Birch Creek and the Snake River valley and is, therefore, not active.

33. A LANDSAT lineament investigation of the Ririe region was conducted by General Electric (GE) Company Space Systems Operations (Space Systems Division, General Electric Corporation 1979). The Ririe study was a part of a larger investigation by GE for the Corps of Engineers (CE) to demonstrate the use of LANDSAT image enhancement techniques in geological investigations. Specifically, this study of the Ririe area was intended to supplement the evaluation of the regional faulting. It was believed that the LANDSAT imagery and the enhancement techniques might define extensions of known, mapped faults and possibly identify linears that might represent previously unmapped faults. Figure 19 is a LANDSAT enhanced image of the area. The GE study identified 20 linears (Figure 20), the most significant of which coincided with known faults; the remainder appeared to reflect topographic features.

Exploratory Drilling

34. A limited objective, core drilling program was initiated in the summer of 1978 for the purpose of determining whether the presumed

Figure 18. Anomalous features northeast of the damsite

Figure 19. LANDSAT custom enhancement - Ririe Dam site, Idaho

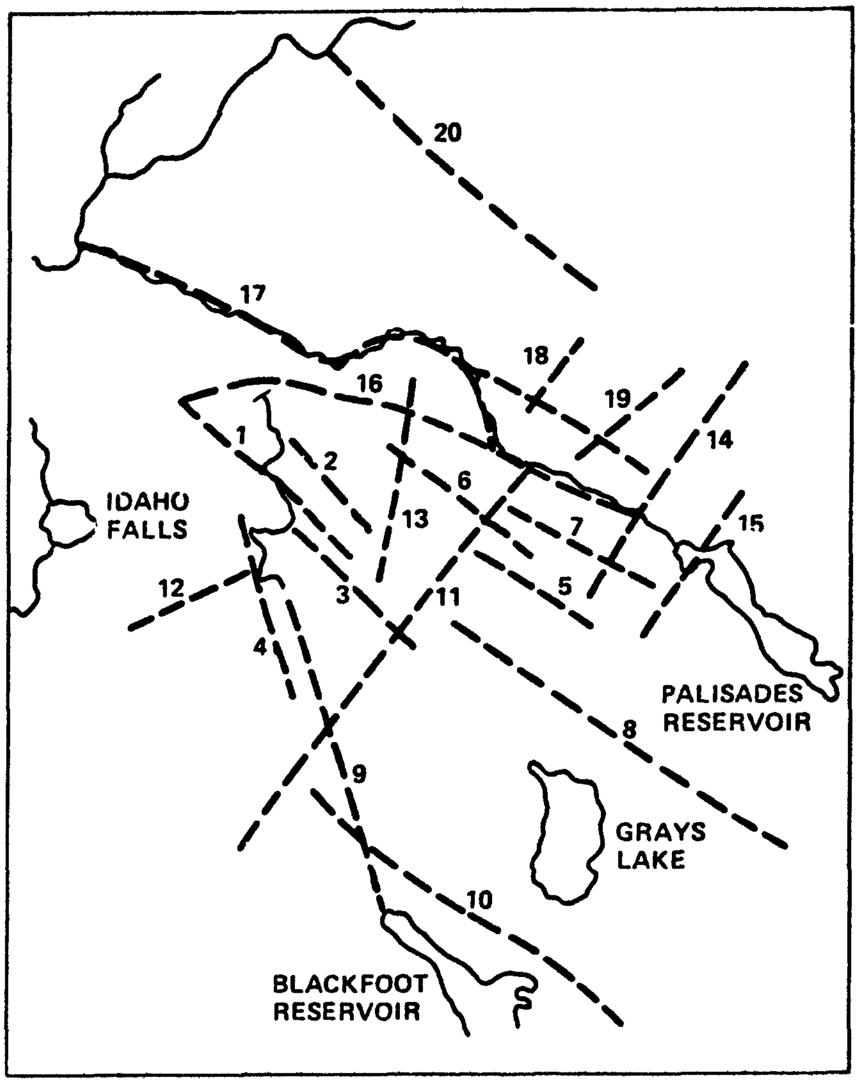


Figure 20. LANDSAT lineaments, Ririe Dam site, Idaho

faults under the dam could be traced along strike beyond the downstream toe of the dam. The strike of the larger fault (N 40° W) suggested that the fault should head into the right canyon wall a short distance downstream of the dam. By drilling out the fault and showing that it did strike into the canyon wall in the subsurface and by previously having demonstrated by observation that the rocks in the canyon wall were not faulted, one could determine a minimum age for the last displacement. This minimum age would be Tertiary, which would result in the fault being classed as noncapable. In the event that the strike of the fault changed and the structure headed farther downstream the objectives would not be satisfied. Also, the drilling was limited to a relatively small spoil area downstream; drilling was prohibited in the natural ground beyond the Willow Creek valley due to environmental restrictions.*

35. The drilling program consisted of nine core drill holes (DH-251 through DH-259) and two pneumatic drill holes (PN-123 and PN-124). The hole locations are shown in Figure 21 and the logs are given in Appendix A. In general, the location of the presumed fault was based upon identifying elevation differences of the basal sediments upper surface (marker horizon 18) between adjacent borings. Three lines of borings approximately normal to the valley strike were drilled. On the first line of borings (nearest the dam toe) an offset of approximately 60 ft on the basal sediments surface was found between holes DH-252 and DH-253. On the second line, farther downstream, an offset of approximately 57 ft occurred between holes DH-254 and DH-255. On the basis of these two drill lines, the presumed fault appeared to maintain its strike and was heading toward the right canyon wall as predicted. The third line of borings was located on the basis of the projected fault strike and as close as possible to the downstream limit of drilling. Four core drill holes (DH-256 through DH-259) and two pneumatic drill holes (PN-123 and PN-124) were drilled in this area. However, the drill

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* Geophysical methods (which were not prohibited) were considered; however, it was believed that neither seismic nor electrical methods could detect marker horizons in the basalt.

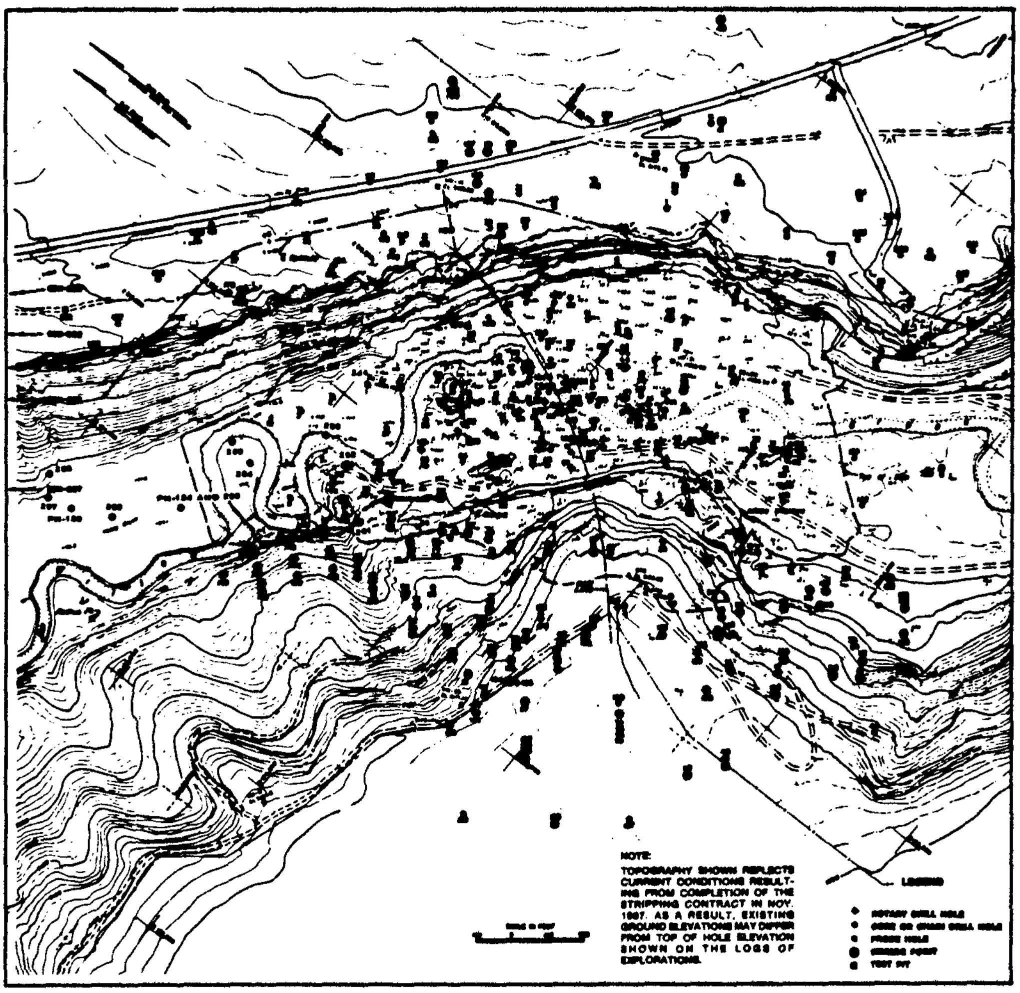

Figure 21. Topographic map showing location of boreholes

holes positioned on both sides of the projected strike line failed to locate appreciable elevation differences on the basal sediments surface. Holes 256 and 257 were located on the downthrown side, indicating that the fault line did not head into the right canyon wall. This third line was then extended toward the left canyon wall. The following two core drill holes and pneumatic holes resulted in the discovery of offset in the basal sediments surface; however, the location of the offset indicated that the strike of the presumed fault line had changed direction possibly by as much as 90 deg.

36. The conclusions resulting from the exploratory boring program indicated that the presumed fault could not be dated by direct stratigraphic evidence and, more importantly, that the irregularity of the strike line strongly suggested a topographic surface rather than a fault scarp. Furthermore, it was apparent that an examination of the topography on the basal sediments surface needed to be conducted throughout the damsite. The results of these investigations are given in the next section.

Interpretation of Presumed Faults at Site

37. This section of the report consists of a review of the geological information concerning the presumed foundation faults, evidence for and against their existence, and an analysis of the structural and stratigraphic relationships between the volcanic units.

38. The evidence for faulting consisted of the following types: (a) dislocations of marker horizons as determined from boreholes, (b) dislocations of marker horizons in the excavation, and (c) a shear zone in the excavation. Presumed fault zones located in the excavation were mapped, cleaned, and covered with concrete.

39. Figure 6 shows a geological cross section along the center line of the dam. This cross section and other sections that follow are ones which appear in various foundation reports and other reports pertaining to the project. These sections reflect minor changes that have been made as a part of this study. In this section two dislocations are

apparent. Approximately 75 ft of displacement occurs between marker horizon 18 on either side of the northeast fault hereafter called Fault 1; approximately 30 ft of displacement occurs between marker horizon 15 on either side of the other fault shown in Figure 6 hereafter called Fault 2.

40. Figure 22 shows the map of the foundation at Fault 1 prepared after excavation of the core trench. This zone is not described as, nor does it appear to be, an area of sheared rock. The material in the zone is either basal sediments (as mapped) or alluvium, consisting of clay and sand; the basalt on either side of these sediments is not particularly sheared nor fractured. Observations made in the core trench exposure suggested that the fault had a strike on N 40° W. Also, the foundation report indicates that the fault is reverse and dips toward the southeast; however, drawings in the foundation report show the fault to be normal. The examination of Fault 2 did reveal the presence of a sheared, brecciated zone.

41. A third fault, Fault 3, was discovered in the left abutment in the intake tower foundation. This fault zone was sheared and nearby borehole evidence indicated that there was an offset in marker horizons 15 and 16. There was approximately 5 ft of dislocation in the excavation of the tower foundation, seen during stripping of the left abutment near the tower site (see paragraph 18).

42. Figures 5 and 6 illustrate the stratigraphic and topographic relationships between the uppermost flow, the intracanyon basalt, and subadjacent units; that is, the indication that the intracanyon basalt as well as the rhyolite occupy topographic lows. Also, it can be seen from Figure 6 that these lows are most likely a former stream channel where this former stream has cut down at least to marker horizon 13.

43. Figure 5 also shows that the elevations of the base of the rhyolite along the dam center line are variable and that the differences in elevations between left and right abutments do not necessarily conform to the sense of movement on the faults. Marker horizons 13 and 14 are topographically irregular; however, topographic offsets conforming to the sense of fault movement are only apparent toward the axis of the dam.

44. The absolute criteria for the recognition of faulting whether in

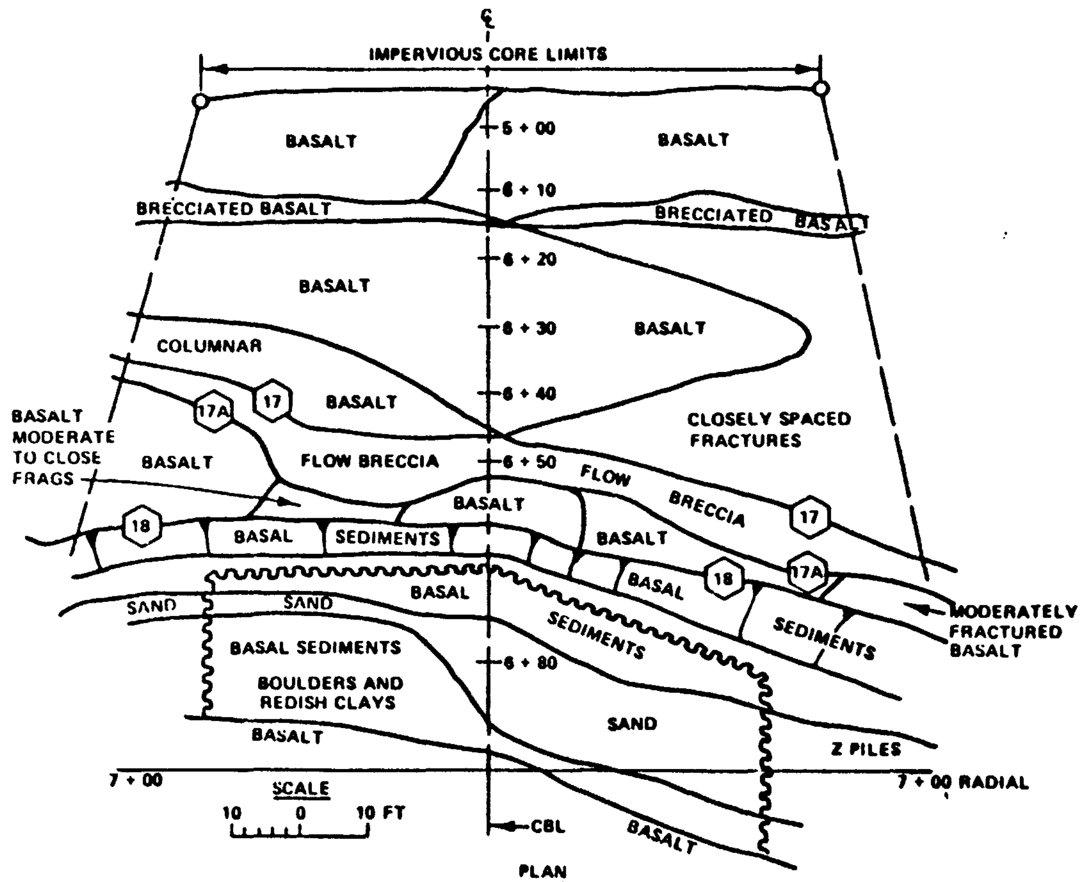

Figure 22. Map of foundation at Fault 1

the subsurface or at the surface is the recognition of offsets in marker horizons or beds on either side of a plane or zone along or through which the offset has occurred. Also, for positive recognition of faulting, the offset horizons should be identified as close to the plane in question as possible. Unfortunately, in this study this absolute criteria has not been met; that is, for a given presumed fault either the offset is recognized or the plane is recognized but in no case have both been observed. The absence of absolute criteria for faulting, the presence of landslides, and the observed high relief on the basal sediments surface suggest that there may, in fact, be no faults in the dam foundation. The following paragraphs address the use of reconstructions and structural contour and isopach maps as well as the occurrence of landslides to interpret the apparent dislocations of marker horizons under the dam.

Landslides

45. An examination of Prostka and Hackman's (1974) geologic maps (Figures 1 and 12) reveals that numerous landslides have occurred on Willow and Meadow Creeks. These features are usually readily apparent in the field; however, landslides of various ages are present. Those slides that have moved the farthest are easiest to identify since they occupy anomalous positions at the base of the canyon walls. Slumps or slides that have moved, as yet, only short distances and that still occupy positions near the top of the canyon walls are less obvious and may be mistaken for faults. Attention was given to distinguishing between faults and landslides during the field studies, and it was concluded that the distinctions between faults and slides were correct.

46. However, the geologic maps can only present information on landslides that are not covered with alluvium. That is, older landslides that predate much of the filling of Willow Creek, for example, would not be seen. There is a body of evidence that indicates that the presumed fault on the left abutment exhibiting approximately 30 ft of displacement is a landslide or slump feature. This slide has been partially covered by alluvium.

47. Figure 21, a topographic map showing the location of boreholes, indicates a small knoll or rise above the alluvium surface near the left abutment. Boring 59 is on the knoll. Figure 23 shows the topography (elevation) on the bedrock surface. This figure also shows the knoll and indicates an anomalous irregular area upon which the knoll is located. This irregular area has the appearance of a landslide or slump feature and is assumed to be such in the interpretation which follows.

Structural reconstruction

48. This technique is based upon the assumptions that faulting has occurred and that topographic influences are not significant. Although the exploratory geological investigations postulated a reverse fault for the major presumed structure (paragraph 40), this was not considered tenable in light of the regional mapped faults, which were all normal. Therefore, the reconstructions assumed normal faulting. Also, the reconstructions assume that the small fault is a landslide or slump feature; therefore, in each reconstruction the slumped block is shown in its preslump position.

49. Figure 24 is a restored section under the dam which is "hung" or aligned on marker horizons 13 and 14. This cross section represents the geology prior to offset of horizons 13 and 14. The section indicates that the assumed fault existed prior to the extrusion of the flows lying above horizons 13 and 14. This is apparent from the offset of horizons 15 and 16 and 17 and 17A. Note, however, that the sense of movement of horizons 15 and 16 and 17 and 17A is different from that of 13 and 14 because 15 and 16 and 17 and 17A have been offset by apparent reverse faulting. This indicates that the direction of movement in the fault has changed. It is also apparent that if a reverse fault had been assumed initially and the restoration made on this basis, that horizons 15 and 16 and horizons 17 and 17A would still exhibit an opposite sense of movement from horizons 13 and 14. Thus, the original assumption that flows 12 and 13 have been cut out by a fault is untenable.

50. Figure 24 is a restored cross section "hung" on marker horizons 15 and 16. This section shows that prior to the presumed

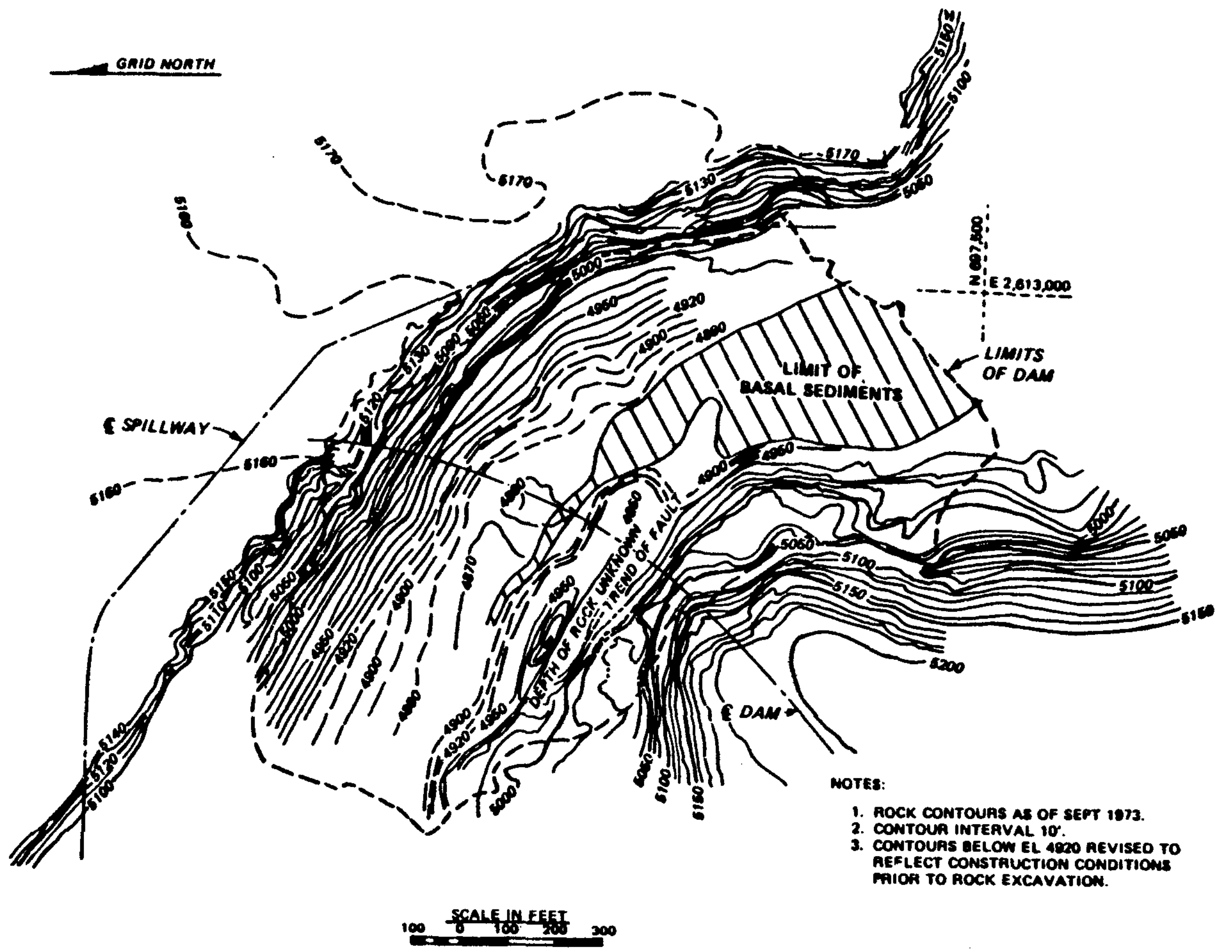

Figure 23. Map of bedrock topography

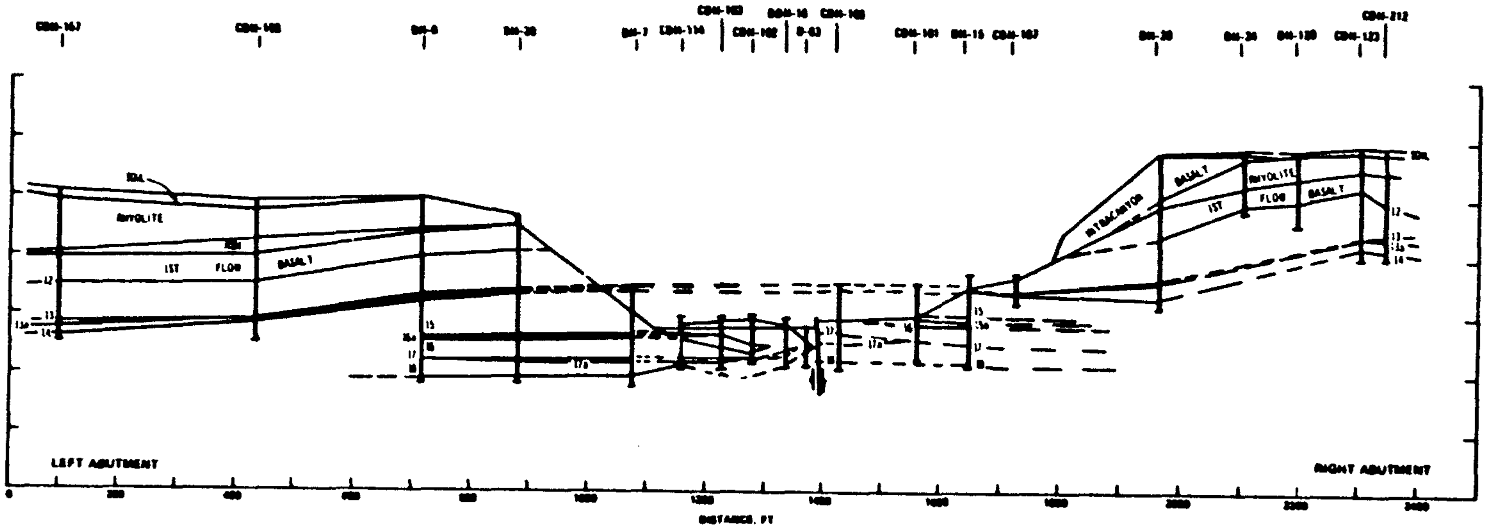

Figure 24. Restored geologic section aligned on contact 14-13

faulting of flows 14 and 15, movement on the fault had displaced marker horizon 18 and flows 16 to 18, and that the sense of movement was normal in both cases. These relative movements indicate that the assumption of faulting of flows 14 and 15 could be correct.

51. The reconstructed cross sections (Figures 24 and 25) as well as the original, unmodified section demonstrate that there is a significant difference in thickness of flows 17 to 18 on either side of the presumed fault. Boring DDH-16 on the left side of the presumed structure gives a thickness of approximately 26 ft; whereas, the thickness on the right side from boring CDH-196 is nearly 44 ft. Generally, this difference in thickness supports the presence of a normal fault since the thicker section is on the down-dropped side.

Structural contour and isopach maps

52. The tabulation below gives the marker horizons upon which structural contour maps were prepared and the flow units for which isopach maps were made:

Marker Horizon	Structural Contour Map Figure	Interval	Isopach Map Figure
12	35	--	--
13	34	--	--
14	33	--	--
15, 15A	32	--	--
16	31	--	--
17	29	16-18	30
17A	28	--	--
18	26	17A-18	27

53. The structure and isopach maps described below were logically contoured and generally do not reflect interpretation. Figure 26 is the structural contour map of the basal sediments surface (marker horizon 18). The closely spaced contour lines trending approximately 1500 ft west from the dam center line is the presumed fault. The map has been logically contoured without interpreting faults; therefore, the position of the presumed fault is indicated by a steep surface of the basal

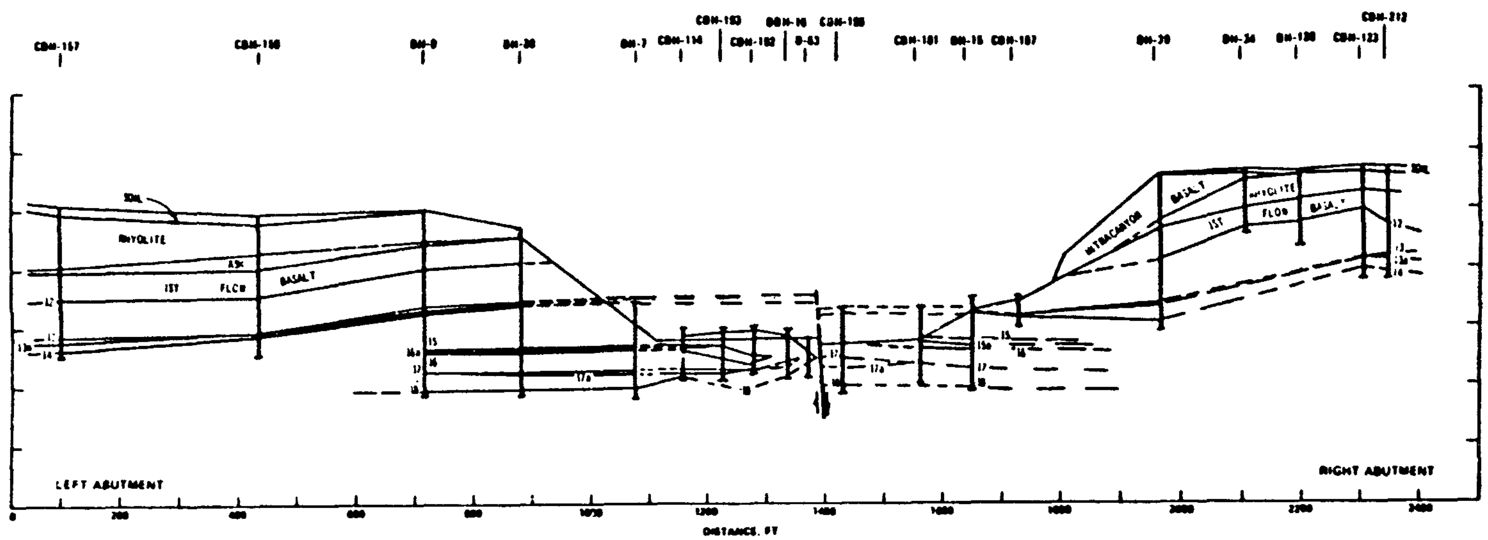

Figure 25. Restored geologic section aligned on contact 16-15

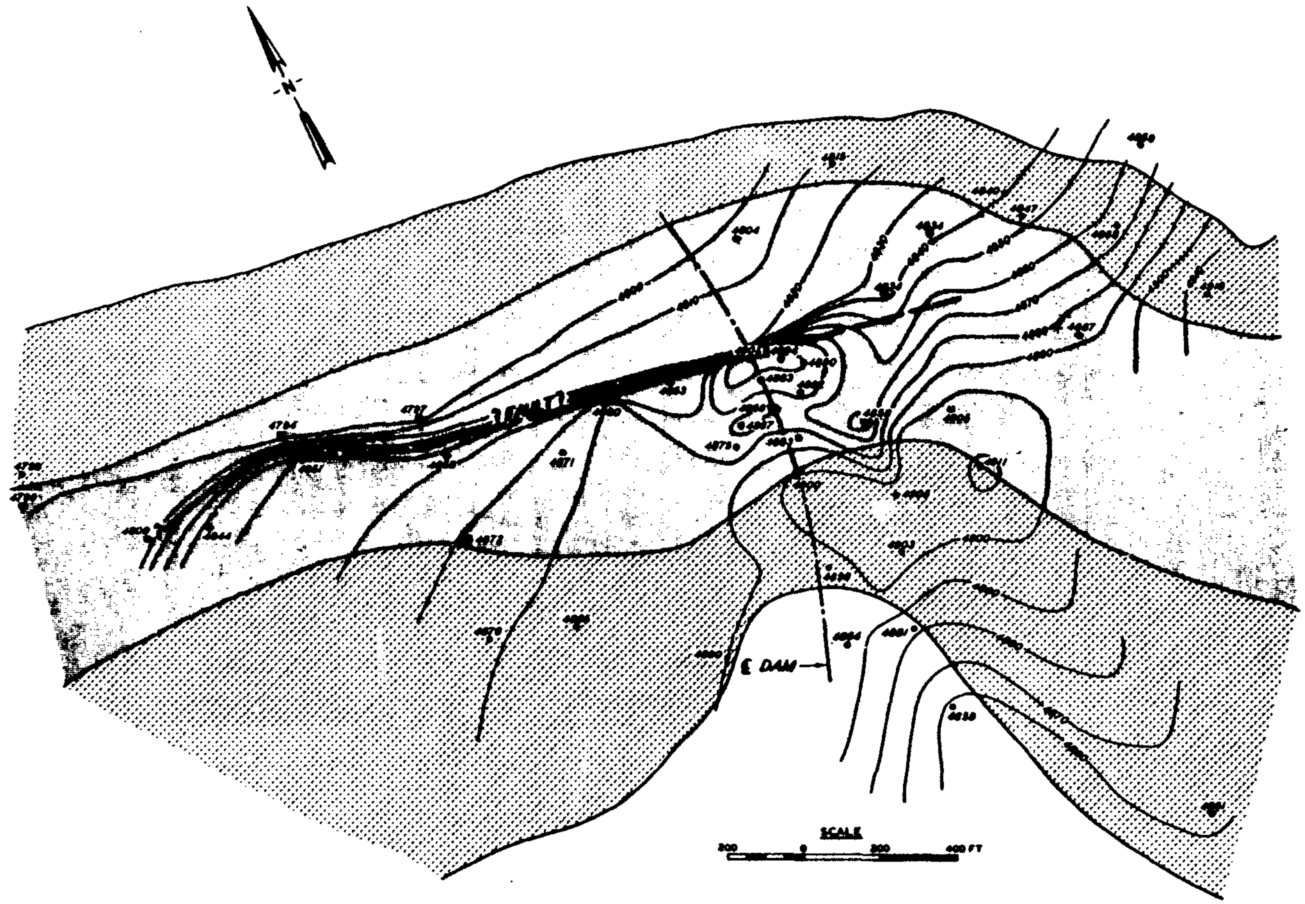

Figure 26. Structural contour map of contact 18 basal sediments

sediments. (If the map had been drawn on the basis of an established fault, the contour lines would stop on the fault line.) Note that the spacing of the contour lines open up within 100 ft east of the dam and also at a point approximately 1500 to the west, indicating that if a fault is present at the dam, the displacement considerably decreases beyond the area of closely spaced contour lines.

54. The interpretation of a logically contoured map must consider and distinguish between anomalies, which are either structural or topographic or both. Thus, the 1500 ft of closely spaced contours could be either a fault line (structural), a cliff or bluff line (topographic), or a fault line scarp (structural and topographic). At least one and possibly two other features shown on the map are probably topographic. One of these features is "hill" 4911 on the left abutment upstream; the other feature is the smaller "hill" 4905 on the dam center line near the landslide feature. Also, the topographic rise indicated by "hill" 4905 may, in part, explain the occurrence of the landslide. That is, the incision of Willow Creek at this point resulted in the exposure of this hill, and thus, a significant portion of the canyon at this point was cut into the basal sediment. Because the clays and sands of the basal sediments were more susceptible to sliding than the overlying flows, failure of these sediments resulted.

55. Figure 27 is a logically contoured isopach map of the interval 17A-18. This map shows that the thickness of this interval ranges from a minimum of nearly 1 ft to a maximum of approximately 48 ft. This map reflects the topography on the basal sediments to the extent that the mapped interval appears to thin somewhat in the area of "hill" 4911; also, there is a distinct thickening to the north. Along the presumed fault line there is an apparent thinning that is particularly evident to the west. The area of thinning could reflect the upthrown side of a fault; whereas, the thickening would represent the downthrown side. However, the changes in thickness could also reflect topography.

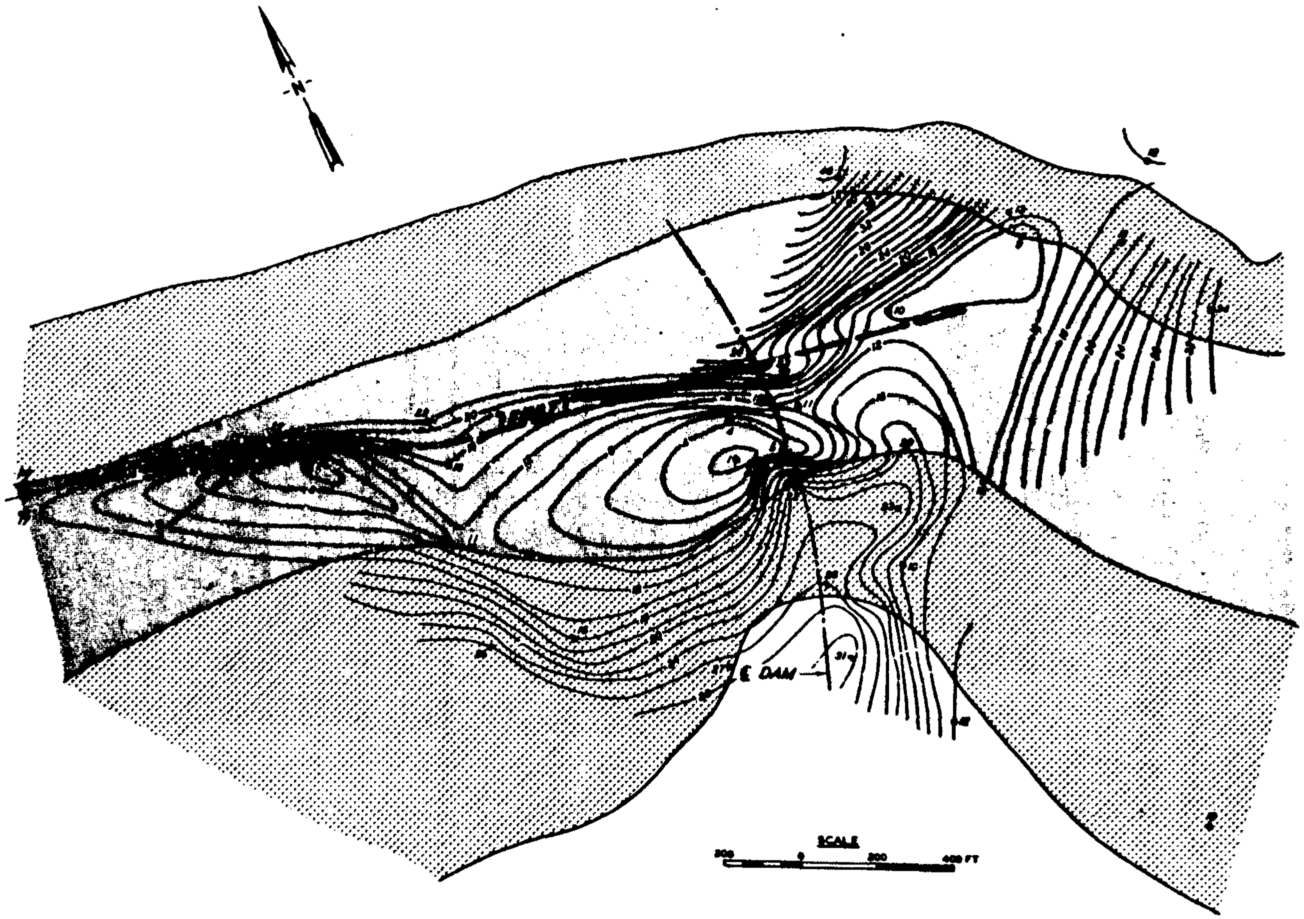

Figure 27. Isopach map of interval 17A-18

56. Figure 28 is the structural contour map prepared for marker horizon 17A. This map also suggests the presence of higher topography in the vicinity of "hills" 4911 and 4905. At the dam center line and to the west there is an apparent steepening of the surface along the trace of the presumed fault.

57. Figure 29 is the structural contour map of horizon marker 17. This surface is similar to that of marker horizon 17A. Generally, the map indicates a surface dipping to the north.

58. Figure 30 shows the isopach map of interval 16-18. The apparently anomalous thinning along the western portion of the presumed fault trace is not continuous along the trace and is not present to the east, upstream of the dam center line. The nonalignment of the thinning anomaly with the trace of the fault near the dam center line could be explained by a flatter dip on the fault plane here relative to the dip downstream of the dam.

59. The structural contour map of marker horizon 16 is shown in Figure 31. The highest elevation, 4975 ft, is located in the general area of "hill" 4911 on the basal sediments surface; a low of 4862 ft occurs in the right abutment. It is apparent that there is no anomaly that conforms to the fault trace. If a fault has cut this surface, erosion has removed the scarp. Note the draw or valley in the right abutment upstream of the dam center line. This feature may be an indication of ancestral valley in the right abutment in which later accumulated the channel gravel and the intracanyon basalt. The anomalous form of the contour lines of the dam center line and south of the fault trace probably reflects the landslide feature.

60. The structural contour map of marker horizons 15 and 15A (combined) is shown in Figure 32. Although the amount of borehole control is diminishing for the upper marker beds, the map does not show any structural relationship between the surface of horizons 15 and 15A and the trace of the presumed fault. Note that the draw in the right abutment is still evident.

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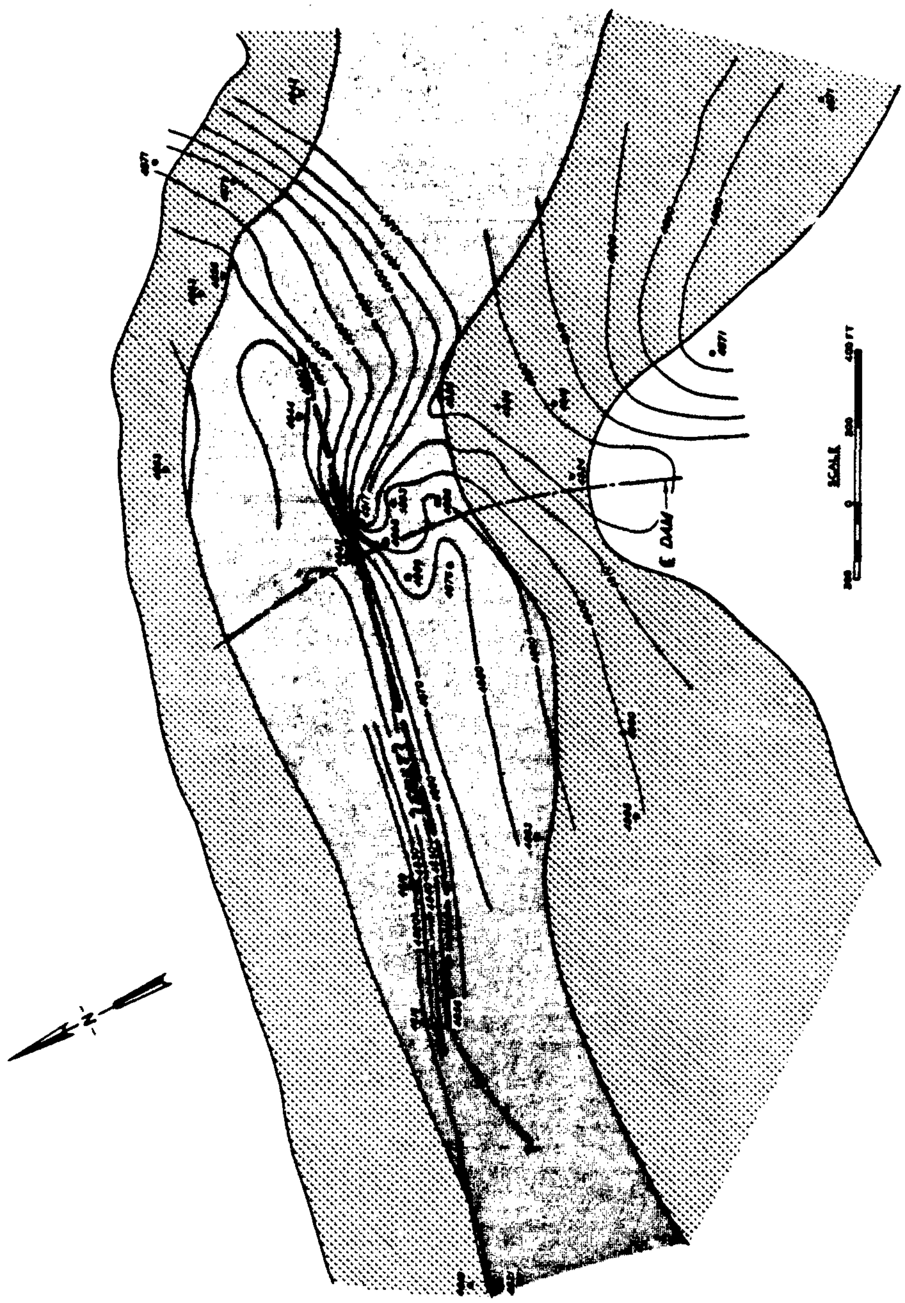

Figure 28. Structural contour map of contact 17A

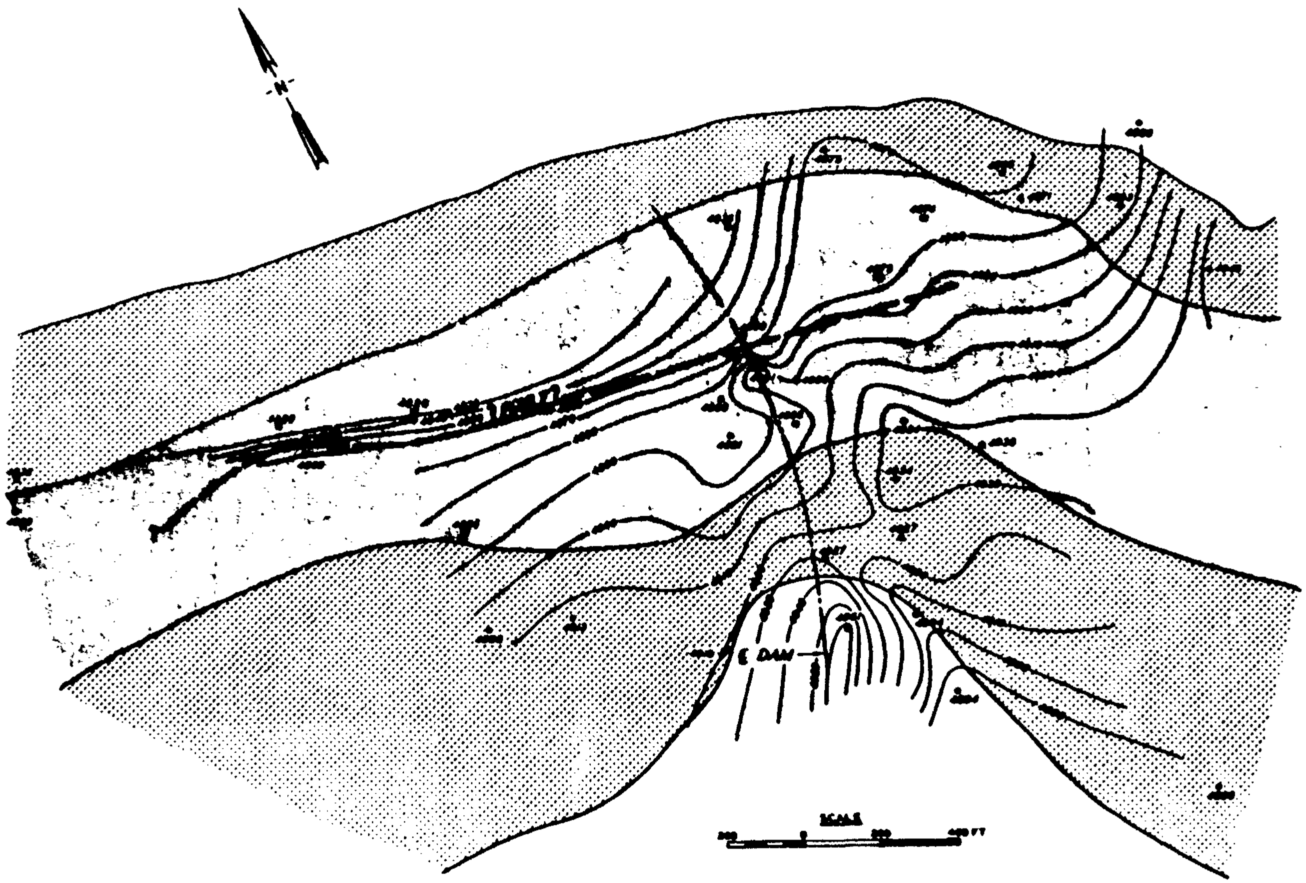

Figure 29. Structural contour map of contact 17

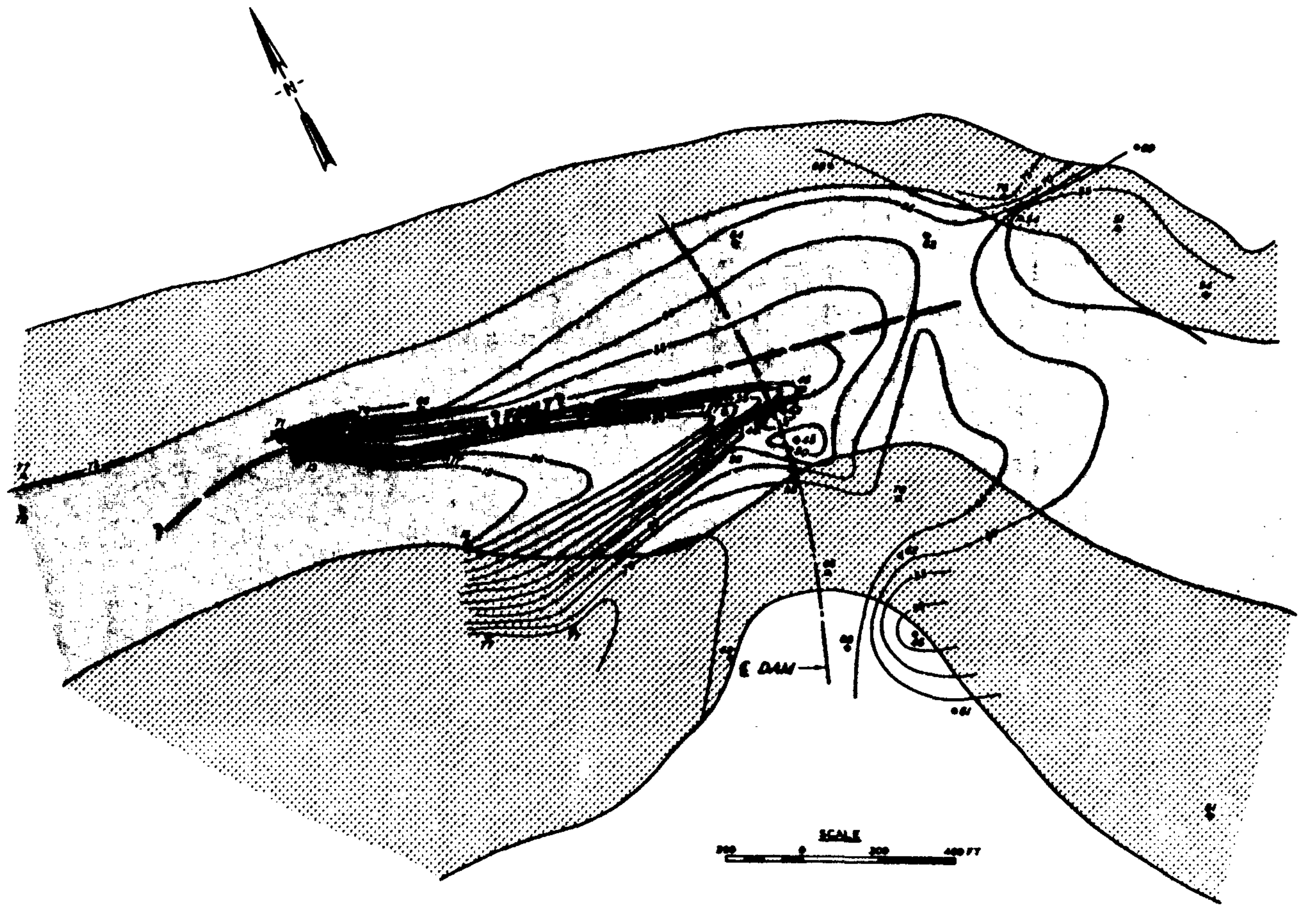

Figure 30. Isopach map of interval 16-18

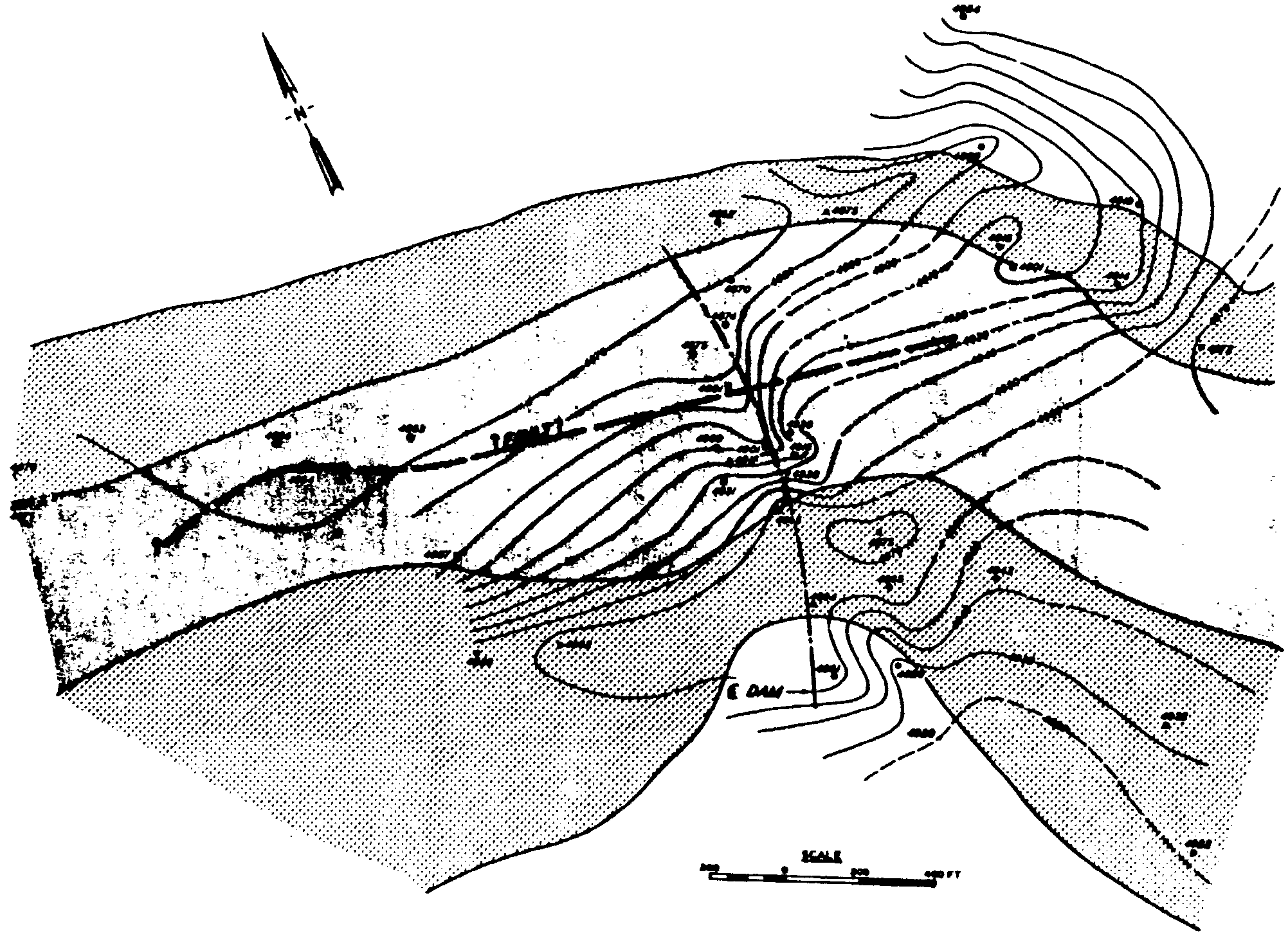

Figure 31. Structural contour map of contact 16

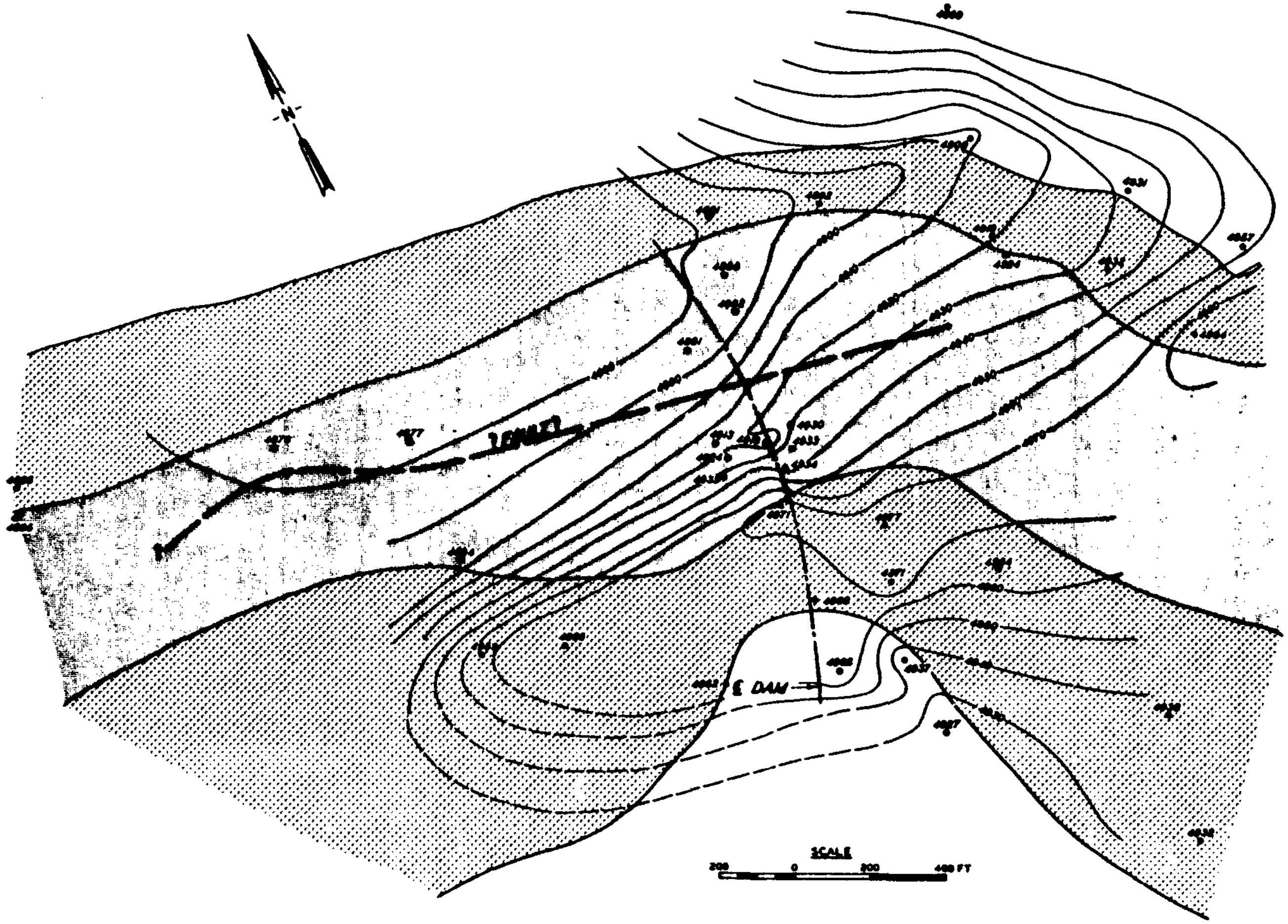

Figure 32. Structural contour map of contact 15 and 15A

61. Figure 33 is the structural contour map of marker horizon 14. The elevations range from a high of 5047 ft near "hill" 4911 on the basal sediments to a low of 4904 ft on the downstream, right abutment. Although borehole control is limited, the contours show the draw on the right abutment. There are no indications of anomalies that could be related to the fault trace.

62. The structural contour map of marker horizon 13, shown in Figure 34, provides no information on the central part of the canyon since the incision of the canyon by Willow Creek has removed this material. The map does show the sides of the draw established in the right abutment. The slopes on the sides of the draw are also shown on the structural contour map of marker horizon 12 (Figure 35).

63. The integration of data derived from the structural contour and isopach maps with information derived from the examination of field relations does not support the existence of faults in the foundation. The abrupt change in strike of the major offset (Fault 1) downstream from the dam, the significant topographic variation on the basal sediments and younger surfaces, the inability to reconstruct rational prefault conditions, the lack of sheared or gouge zones, and the presence of landslides strongly support the conclusion that the identified offsets in the foundation are topographic and that there are no active or capable faults at the damsite.

Regional Faulting

64. This section of the report will describe the significance of geologic structures beyond the damsite. The analysis of these structures was based upon published information, geologic maps, and primarily upon interpretations of USGS data on young faults in the area.

65. Figure 36 shows the location of young mapped faults in the study area. This is a modification of USGS Map MF-916, "Preliminary Map of Young Faults in the United States as a Guide to Possible Fault Activity, Miscellaneous Field Studies" (Howard et al., 1978). Figure 36 also shows the earthquake epicenters.

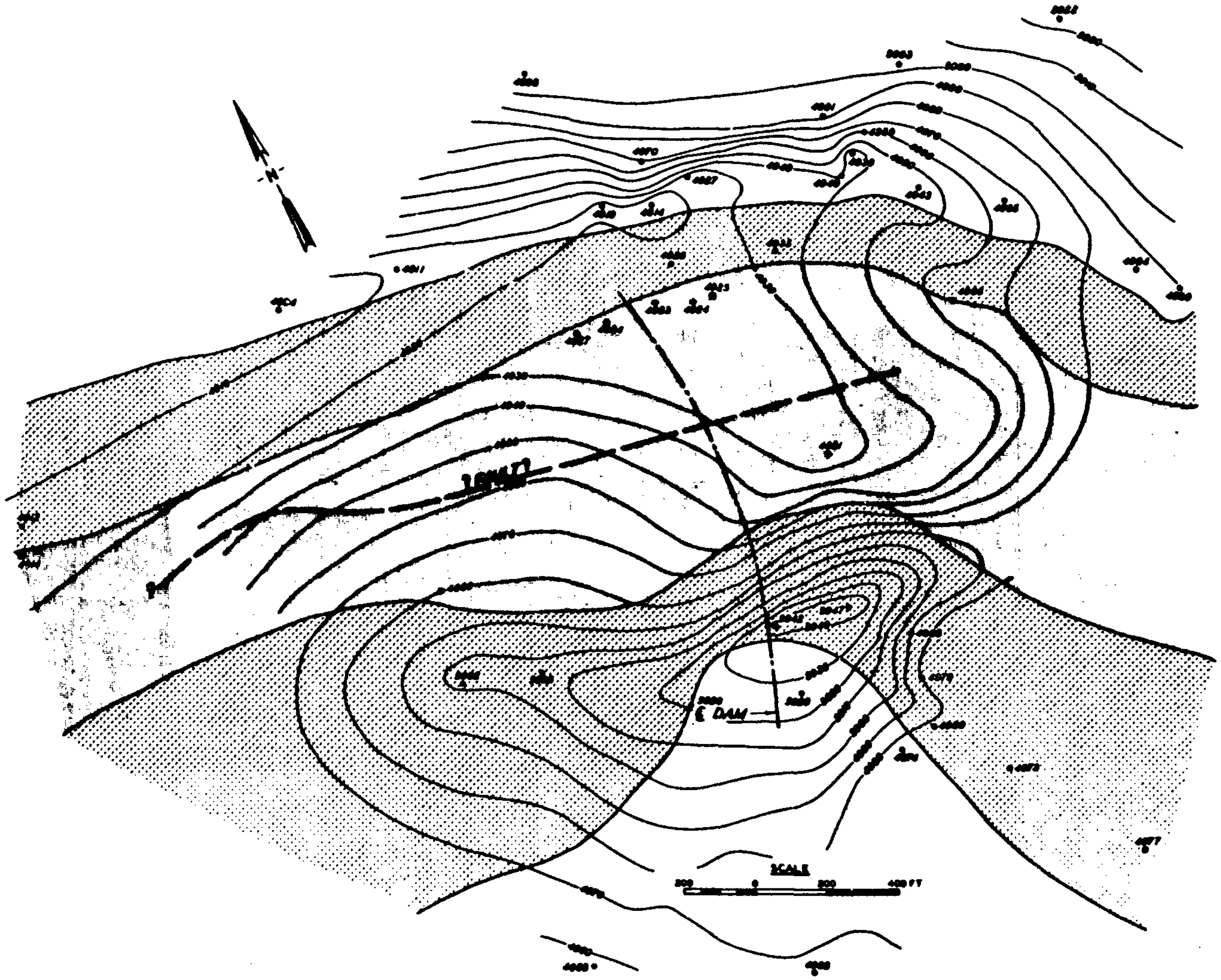

Figure 33. Structural contour map of contact 14

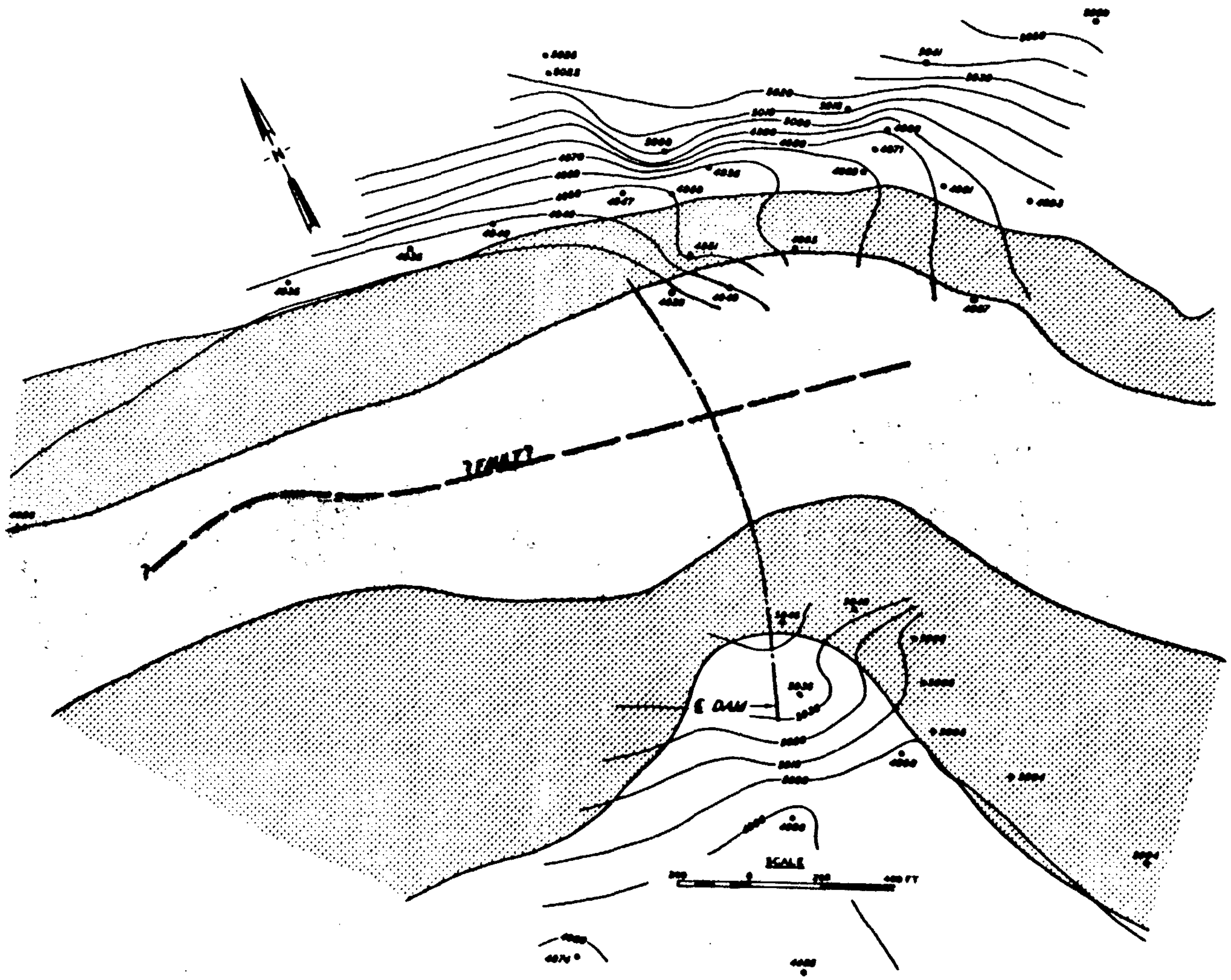

Figure 34. Structural contour map of contact 13

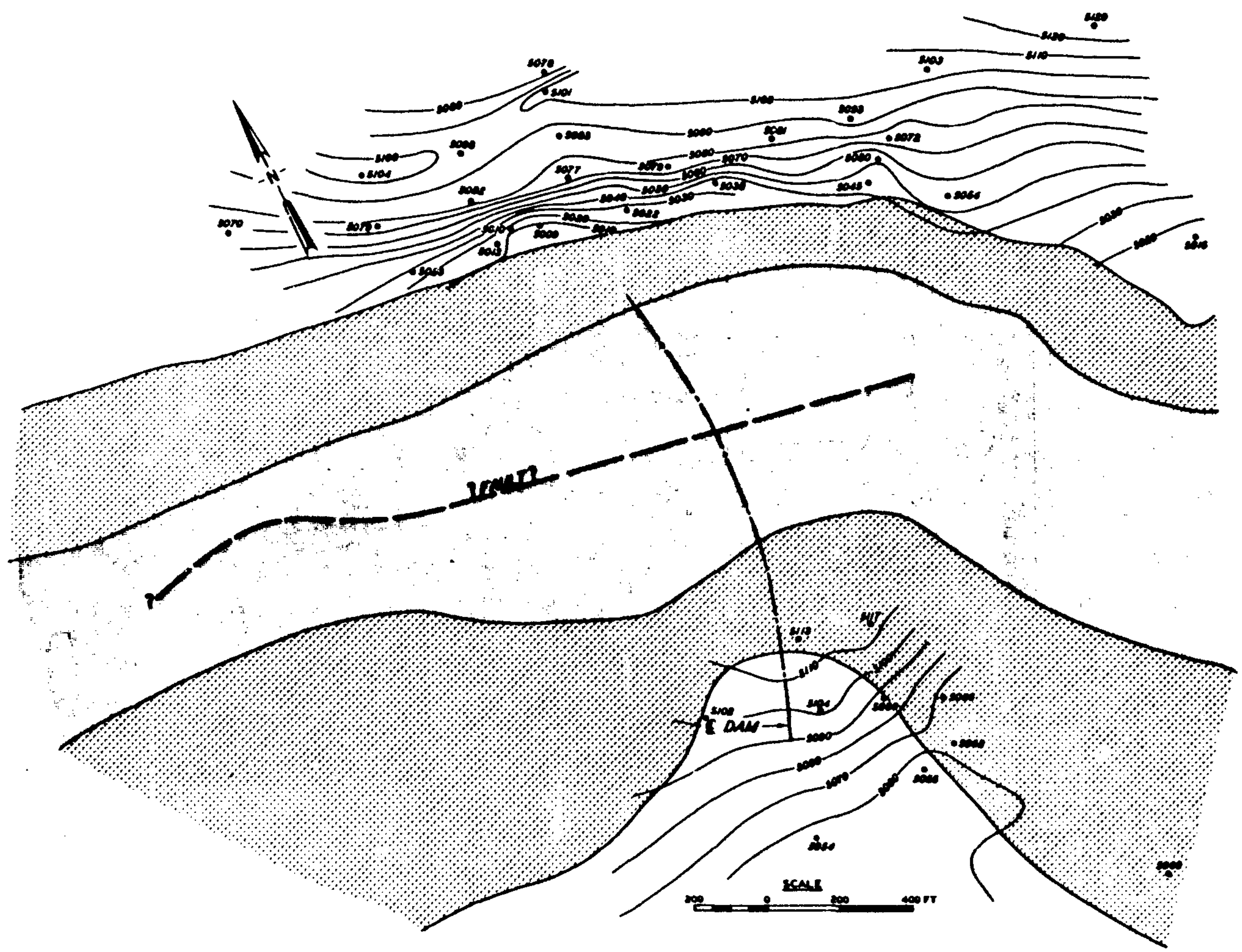

Figure 35. Structural contour map of contact 12

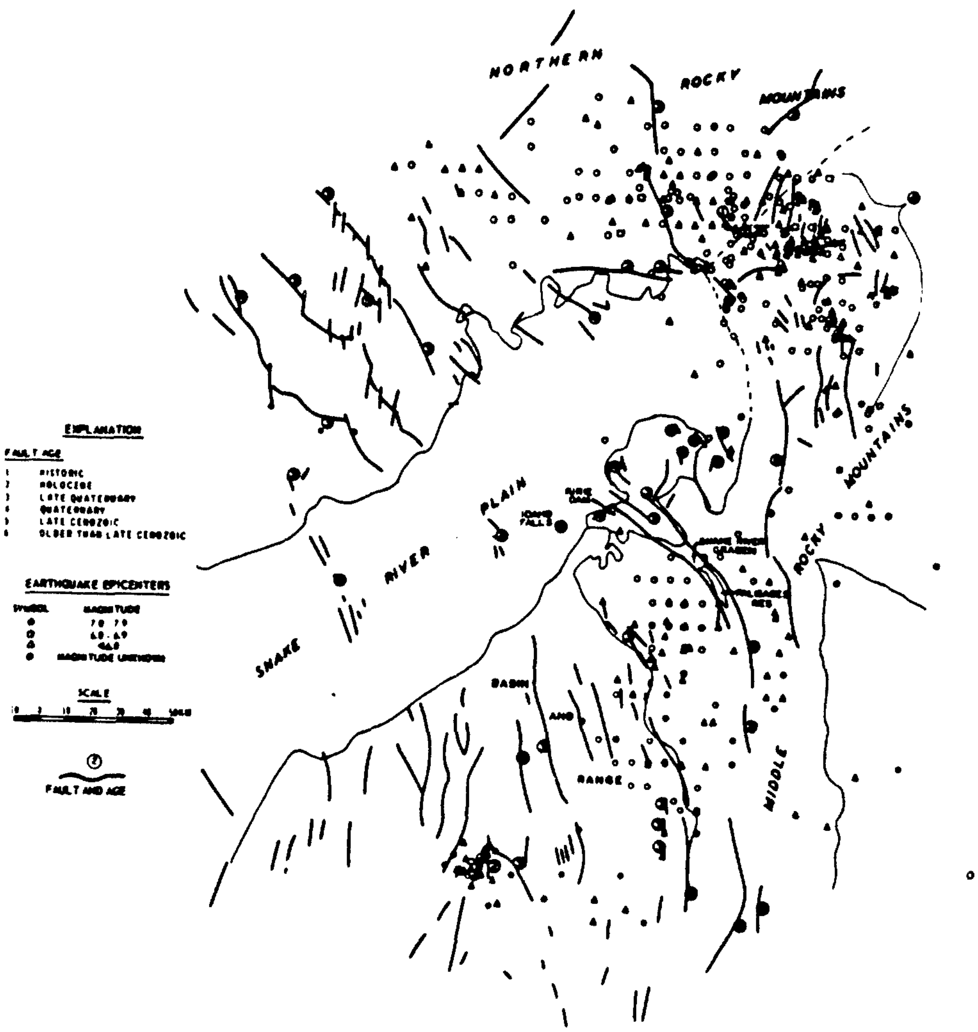

Figure 36. Young mapped faults and earthquake epicenters (from Howard et al., 1978)

66. Those faults that would be of principal interest with respect to activity or capability are those along which movement has occurred during historic, Holocene, and late Quaternary times, labeled respectively 1, 2, and 3 on the map. The fault map shows that only one fault exhibited historic movement; however, numerous faults exhibited movement during Holocene and late Quaternary times. Also, the map does not show any strong apparent correlation between faulting and earthquake epicenters. In the absence of information on recurring movement for those faults of late Quaternary age, the following discussion of significant faults will be limited to historic and Holocene faulting.

67. Historic faulting occurred in the Hebgen Lake area approximately 150 km north-northwest of the site during the 17 August 1959 Hebgen Lake earthquake (M = 7.1). Holocene faulting occurred in southwestern Montana; along the northeast side of the Snake River graben; in the vicinity of the earthquake cluster along the Utah-Idaho border; and at several locations on the Snake River Plain. Pertinent information on these faults is given in Table 1.

Table 1

Regional Historic and Holocene Faulting

Fault	Location	Closest Distance to Ririe (km)	Fault Length (km)	Age*	Maximum Theoretic Earthquake Magnitude
Hebgen Lake	SW Montana	150	~25	Historic	7.0
Red Rock Creek	SW Montana	120	60	Holocene	7.4
Grand Valley	Snake River graben	20	110	Holocene	7.7
Unnamed	Utah-Idaho border	180	~8	Holocene	6.6
Unnamed	Snake River Plain	60	8	Holocene	6.6
Idaho Rift system	Snake River Plain	140	29	Holocene	7.0**

* Age based upon map by Howard et al. (1978).

** This magnitude is unrealistic in terms of the geologic environment of the rift system. A more reasonable value is in the range of magnitude 5.0 to 5.5.

68. The significance of these faults to the seismic evaluation of the site is dependent upon the location of the fault with respect to the site, the fault length and potential size of earthquake generated, and the degree of reliance placed on the evidence that the fault is, indeed,

active or capable. Also, these factors must be correlated with historic seismicity as well as with the geology of the area in question.

69. Based upon the consideration of the factors given above, the Hebgen Lake and Red Rock Creek faults in southwest Montana, the Grand Valley fault along the Snake River graben, and the unnamed fault along the Utah-Idaho border are considered most significant with respect to size, local seismicity, or nearness to the site. Those small faults located on the Snake River Plain are not considered to significantly affect the Ririe Dam site.

70. The Hebgen Lake and Red Rock Creek faults are both in areas of high seismicity, which appear to be reasonably distinct zones. The unnamed fault along the Utah-Idaho border also occurs in an area of numerous earthquakes.

71. The most significant fault is the Grand Valley fault system located east of the site. Although no macroearthquakes can be positively associated with this system, its length and nearness to the site indicate that its potential for generating earthquakes must be considered.

72. Figure 37 shows the details of the Grand Valley fault system. This illustration was prepared from the previously mentioned USCS Map MF-916 (Howard et al., 1978) and USCS Open-File Report 75-278 entitled "Preliminary Map Showing Known and Suspected Active Faults in Idaho" (Witkind, 1975). This latter publication was the working document upon which the Idaho portion of MF-916 was based.

73. Discussions with various USGS personnel were conducted to determine the basis for the Holocene age of the Grand Valley fault. Generally, the results of these discussions were that the determination of fault age was subjective and was not based upon definitive stratigraphic or seismological evidence. Furthermore, one basis for the age was the occurrence of small earthquakes in the Caribou Range some 20 km west of Palisades Reservoir. These earthquakes were believed to have been induced by the reservoir, and the Grand Valley fault, which occurs along the north side of the reservoir, was believed to have been active. A discussion of reservoir-induced seismicity at Palisades Reservoir is

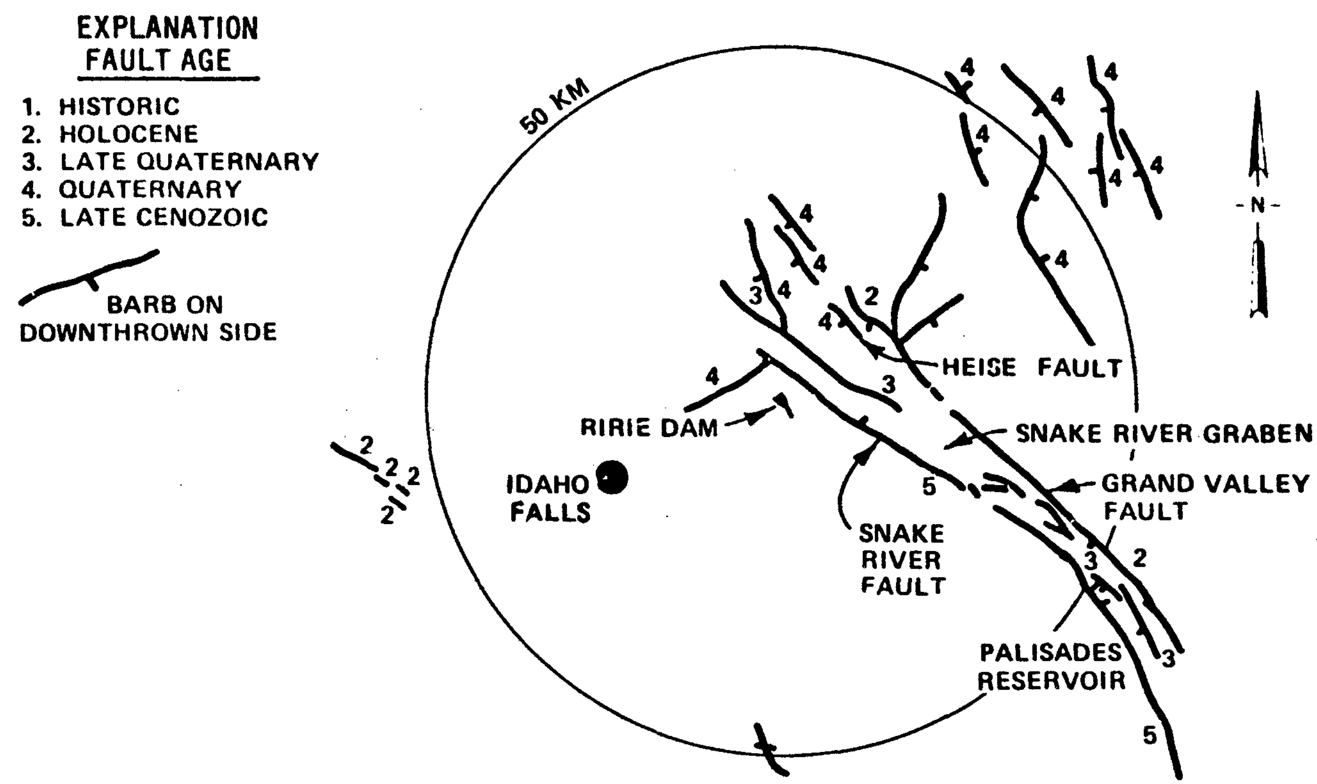

Figure 37. Grand Valley fault system, showing faults within 50 km of Ririe Dam

given in PART IV. However, earthquakes in a reservoir area would not, according to CE criteria, require that faults in the area be considered active or capable.

74. The data sheet that describes the Grand Valley fault and that provides available information for the classification of faults shown on the Idaho portion of MF-916 was also examined. The data sheet indicated that the fault had a high susceptibility for generating earthquakes although there were no known surface breakages. The age of the fault was given as late Cenozoic. Note that the age of the fault in Figure 37 is Holocene. This discrepancy in age may be due to error or to the belief that Palisades Reservoir has induced seismicity on the fault. The examination of USGS Map MF-287 (Jobin and Schroeder, 1964) which shows the geology of Swan Valley southeast of Palisades Reservoir reveals that in this area the Grand Valley fault is covered by Quaternary alluvium and is Tertiary in age.

75. In order to obtain further information on regional faulting, aerial reconnaissance of the Ririe area was conducted using low sun angle observations. The primary purpose of this work was to examine the damsite and Snake River graben area in order to determine whether fault offsets could be detected. These observations revealed no conclusive evidence for recent fault offsets on the Grand Valley fault flanking the graben nor at the damsite. However, aerial observations revealed the presence of subdued scarps along the northern extension of the Heise fault (Figure 37) on the Snake River Plain; this extension of the Heise fault is the Rexburg fault. These scarps or offsets could not be traced to the Heise fault and none were seen along the mapped trace of the Heise fault. The observed scarps were evident for a distance of approximately 10 km.* Williams and Embree (1980) trenched the Rexburg fault at a location approximately 2.8 km south of Rexburg and found faulted

* David B. Slemmons, Consulting Geologist, personal communications.

middle to late Pleistocene deposits underlying unfaulted late Pleistocene alluvial sediments. The older deposits were offset 1.6 m. No Holocene movement was indicated.

76. Overall, the review of regional faulting did not reveal faults that could conclusively be classed as capable according to ER 1110-2-1806 (Office, Chief of Engineers, 1977), that is no observed movement within the last 35,000 years, no seismicity, and no association with a known capable fault. Although these regional faults are not capable according to this definition, their relatively young age, uncertainty as to exact age, and nearness to the damsite must be considered in the determination of maximum earthquakes.

PART IV: SEISMICITY

General

77. Ririe Dam is located in the Intermountain Seismic Belt (ISB); the relations between seismicity and tectonics in this area have been described by Smith and Sbar (1974). The ISB is a region of high seismicity and is classed by Algermissen (1969) as a zone of major damage (Zone 3). Greensfelder (1976) has examined the tectonics and seismicity in Idaho and determined the maximum probable bedrock accelerations for the state. The work of Smith and Sbar (1974) and Greensfelder (1976) will be related to this study in subsequent sections of PART IV and in PART V of this report.

78. This part of the report will provide information pertaining to the historical earthquake record, levels of seismicity, locations of earthquake events, concentrations of activity, recurrence, attenuation of seismic energy, and potential for induced seismicity. This information plus that determined from studies of the geology and faulting will form the basis for the selection of the design earthquakes presented in PART V.

Historical Earthquakes

79. The identification of a radius of interest for which historic earthquake information is needed is site-dependent; specifically, the area of investigation is inversely proportional to the level of seismic activity at cr near the site and the presence of active or capable faults at or near the site. At Ririe Dam the known earthquake activity is relatively low and there are no known active or capable faults. Therefore, the radius of investigation must extend considerably beyond the site. This distance should include all earthquake sources or source areas that are believed to possibly affect the site. Since the largest earthquake event in the region was the Hebgen Lake earthquake in West

Yellowstone and the area of highest seismicity is the Yellowstone National Park (YNP) area, a radius of 200 km was selected to incorporate the area of investigation.

80. The basic data on historical seismicity was obtained from the following sources: (a) Earthquake History of the United States (Environmental Data Service 1973), (b) United States Earthquakes, 1971-76 (Environmental Data Service 1973-78), (c) National Oceanic and Atmospheric Administration (NOAA) computer printouts, and (d) NOAA computer-printed epicenter map. Source (a) is a compilation of earthquake events and their descriptions through 1970; source (b) is a yearly compilation through 1976. Both sources (a) and (b) contain data that have been carefully reviewed and refined. Source (c) is a computer listing of earthquakes in the geographic area (200 km from the dam) retrieved from NOAA's earthquake data file. This source provides information on more recent events; however, the data has not been subjected to rigorous review.

81. The first step in the analysis of the seismicity is to prepare a list of earthquakes. This list includes all detected events greater than or equal to Modified Mercalli (MM) intensity IV or magnitude 3.0. The table is the base from which the recurrence is determined. Appendix B contains the earthquake list for the area within 200 km of Ririe Dam. The first entry in the list is for the year 1880 and the table includes 1977 activity. The examination of the table reveals an apparent increase in seismic activity with time. This appearance is believed due to low population density in the early years of settlement and the increase in the number of seismograph stations capable of detecting events in the area.

82. The NOAA computer-printed epicenter map is shown in Figure 36. The epicenter map shows that the areas of higher seismic activity are the Yellowstone National Park region and an area to the south of the site on the Utah-Idaho border. The Snake River Plain is seen to be relatively aseismic as is the site itself. However, one event having a magnitude less than 6.0 is located a few kilometres south of the site.

No further information regarding this event could be found. Further to the south in the Middle Rocky Mountains and Basin and Range Provinces, there are numerous low magnitude events.

83. The second step in the analysis is the comparison of the significant events given in Table 2 with those shown on the epicenter map (Figure 36). Significant earthquakes are those events having epicentral intensities equal to or greater than MM VII. MM VII or magnitude 5.5 earthquakes are the lower limits for earthquakes that could produce damage to structures. Thirteen significant events have occurred. Three of these are located along the Utah-Idaho border, and the rest are located in Yellowstone National Park and vicinity. These events are shown in Table 2 and are described in subsequent paragraphs.

Significant Earthquakes

84. The following is a general summary of the significant earthquakes that have occurred within a radius of 200 km of the site (see Table 2).

11 Nov 1905

85. This MM intensity VII event occurred near Shoshone, Idaho, and was felt in southern Idaho, northern Utah, and eastern Oregon. Minor damage occurred at Shoshone. This event was located approximately 235 km southwest of Ririe Dam on the Snake River Plain and is not shown on the earthquake epicenter map (Figure 36), nor on the master earthquake list (Appendix B) since it lies beyond 200 km of the site. However, the event is significant because it is the largest event to occur on the Snake River Plain and is, therefore, important in the identification of the maximum credible earthquake to occur on the Snake River Plain.

13 May 1914

86. This MM intensity VII event was felt over an area of 8000 sq mi. Windows were broken and chimneys were toppled at Ogden, Utah, and it was felt at Salt Lake City, Utah. Movement on the Wahsatch fault near the Utah-Idaho border is believed to have resulted in this earthquake. No ground breakage was reported.

Table 2

List of Significant Earthquakes

Year	Date	Locality	Coordinates Deg. N. Lat.	Coordinates Deg. N. Long.	Magnitude	Epicentral Intensity (MM)	Felt Area	Dist. to Ririe (km)	Int. at Ririe	Focal Depth
1905*	11 Nov	Shoshore, Idaho	42.9	114.5	--	VII	--	235	--	--
1914	13 May	S. E. Idaho	42	112	--	VII	8,000 sq. mi.	175		
1947	23 Nov	S. W. Montana	44.8	112.0	M = 6.2	VIII	150,000 sq. mi.			
1959	17 Aug	Hebgen Lake, Montana	44.8	111.1	M = 7.1	X	600,000 sq. mi.		V	
1959	18 Aug	Yellowstone National Park	45.0	110.5	M = 6.5		--			
1959	18 Aug	Yellowstone National Park	44.8	110.7	M = 6.0	VI				
1959	18 Aug	Hebgen Lake, Montana	44.8	111.1	M = 5.5					
1959	18 Aug	Yellowstone National Park	44.9	110.7	M = 6.5					
1959	18 Aug	S. W. Montana	44.9	111.6	M = 6.0	V				
1962	30 Aug	Cache Valley, N. Utah	41.8	111.8	M = 5.7	VII	65,000 sq. mi.			
1964	21 Oct	Hebgen Lake, Montana	44.8	111.6	M = 5.8	V	3,000 sq. mi.			
1975	27 Mar	Malad City, S. E. Idaho	42.06	112.55	M_6 = 6.1	VIII	160,000 km^2		II-III	
1975	30 Jun	Yellowstone National Park	44.75	110.61	M_6 = 5.6 M_L = 6.4	VII	50,000 km^2		not felt	
1976	8 Dec	Yellowstone National Park	44.76	110.79	M_6 = 5.5	V	--			

* Not listed in Table B1 nor shown on eipcenter map.

23 Nov 1947

87. This event occurred in central Madison County, Mont., and had a magnitude of 6.2 and epicentral MM intensity of VIII. The event was felt over an area of 150,000 sq mi and produced considerable damage locally. No ground breakage was reported.

17 Aug 1959

88. The Hebgen Lake, Mont., earthquake having an MM epicentral intensity of X and a magnitude of 7.1 was the largest event recorded in the study area. This event was felt over 600,000 sq mi and produced much damage and loss of life locally. Minor damage also occurred in northeastern Idaho and northwestern Wyoming. Approximately 150 aftershocks were reported in the Yellowstone National Park area; included among these were the events listed below.

18 Aug 1959

89. On this date five significant aftershocks from the Hebgen Lake earthquake occurred. Three aftershocks occurred in Yellowstone National Park. Two of these events had magnitudes of 6.5 and the third had a magnitude of 6.0. One magnitude 5.5 event occurred at Hebgen Lake, and a magnitude 6.0 event occurred approximately 40 km to the west of Hebgen Lake.

30 Aug 1962

90. This magnitude 5.7, MM intensity VII event originated on the East Cache Valley fault located approximately 25 km south of the Utah-Idaho border. Landslides occurred and damage was estimated to be over $1,000,000.

21 Oct 1964

91. This rather low intensity event produced some modest damage in its epicentral area near Hebgen Lake, Mont.

27 Mar 1975

92. This event occurred in the Pocatello Valley approximately 25 km southwest of Malad City, Idaho. The earthquake exhibited an epicentral MM intensity of VIII and a body-wave magnitude (M_b) of 6.1. The event was preceded by a magnitude 4.4 foreshock and was followed by

approximately 14 aftershocks. No surface faulting was evident. Damage was valued at approximately $1,000,000.

30 Jun 1975

93. This MM intensity VII, magnitude 5.6 (M_b) event occurred in Yellowstone National Park and was felt of an area of 50,000 sq km. Damage was generally minor, although numerous landslides occurred in the National Park.

8 Dec 1976

94. This earthquake having a magnitude (M_b) of 5.5 and an MM intensity of V also occurred in Yellowstone National Park. Very minor damage was produced.

95. A magnitude 6.0-6.9 event located at coordinates 44.75° N. Lat. and 111.75° W. Long., is given on the NOAA epicentral map. No collaborating information could be found for this event.

Seismic Zonation

96. Seismic zonation is the identification and delineation of zones or regions which, based upon their geologic, structural, and seismic nature, exhibit distinct and different earthquake characteristics. The nature and characteristics of the individual seismic zone includes active and capable faults, earthquake size, and earthquake recurrence. The use of seismic zones is based, therefore, upon the recognition that the region is composed of distinct seismic source areas.

97. Although observation of the data on the epicenter map strongly suggests that the area within 200 km of the site is not at all uniform, the analysis of recurrence data* confirms the variations. Figure 38 is a plot of recurrence curves for areas within 75, 100, 160, and 200 km of the site. Generally, these curves demonstrate that the level of seismicity increases with the size of the area. At distances less than 75 km from the site, there was insufficient activity to construct a

* Recurrence curves for the seismic zones as well as definitions are given in the next section.

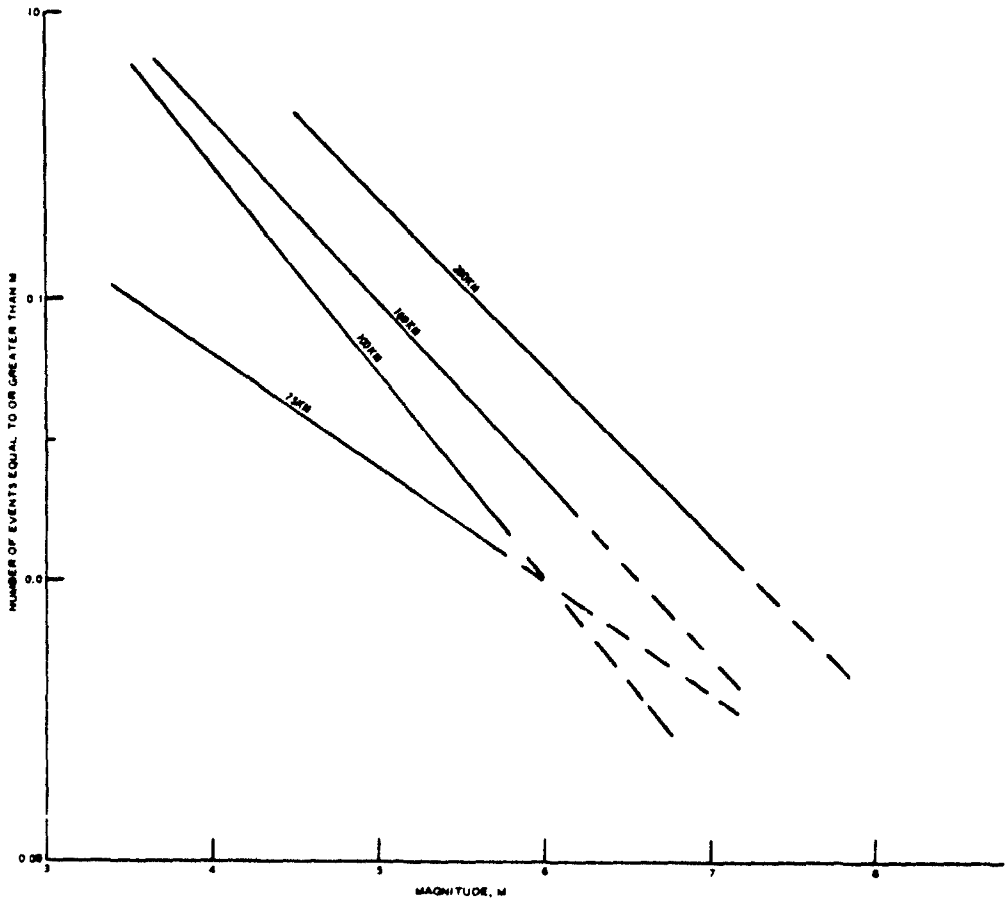

Figure 38. Recurrence curves for areas within 75, 100, 160, and 200 km of Ririe Dam

recurrence curve. The use of this arbitrary, geographical zonation demonstrates in a semiquantitative manner the need for development of a rational seismic zonation incorporating geological and structural data to designate areas of distinct seismic character.

98. Three seismic zones were established and are shown in Figure 39. The two areas of more concentrated seismic activity were delineated as zones A and B. These zones include all of the historic events within a 200-km radius of Ririe Dam, except for a few isolated, scattered events. The zones cannot, therefore, be interpreted as being rigid or fixed seismic zones, but rather can be interpreted as general seismic zones whose effects can be related to the Ririe Dam area. Zone A encompasses the general area of Yellowstone National Park and portions of western Montana. Zone B includes those areas of earthquake activity south of site including the area on the Utah-Idaho border. Zone C includes the site and adjacent areas not in Zones A or B.

99. Zone A, the most obvious of the three zones, appears to exhibit the highest level of seismicity. The largest earthquake events in the zone are confined to a relatively narrow band approximately 100 km long and approximately 40 km wide. The overall seismic activity appears to be rather evenly distributed, however, across rather diverse geologic structures including the Northern and Middle Rocky Mountain fold belts and volcanic terrane of Yellowstone National Park. The closest approach of Zone A to the site is approximately 105 km.

100. Zone B is somewhat less well-defined seismically than Zone A, even though the geology and structure are less diverse. Zone B includes a portion of the Middle Rocky Mountains Province to the west and southwest of the damsite and a larger area to the south in the Basin and Range Province. This zone extends to within approximately 40 km or so from the damsite. Note that this zone has not been drawn to include the Snake River graben area southeast of the site since there have been no recorded earthquakes in this area. However, the Snake River graben area is geologically similar with respect to type of faulting to the Basin and Range Province.

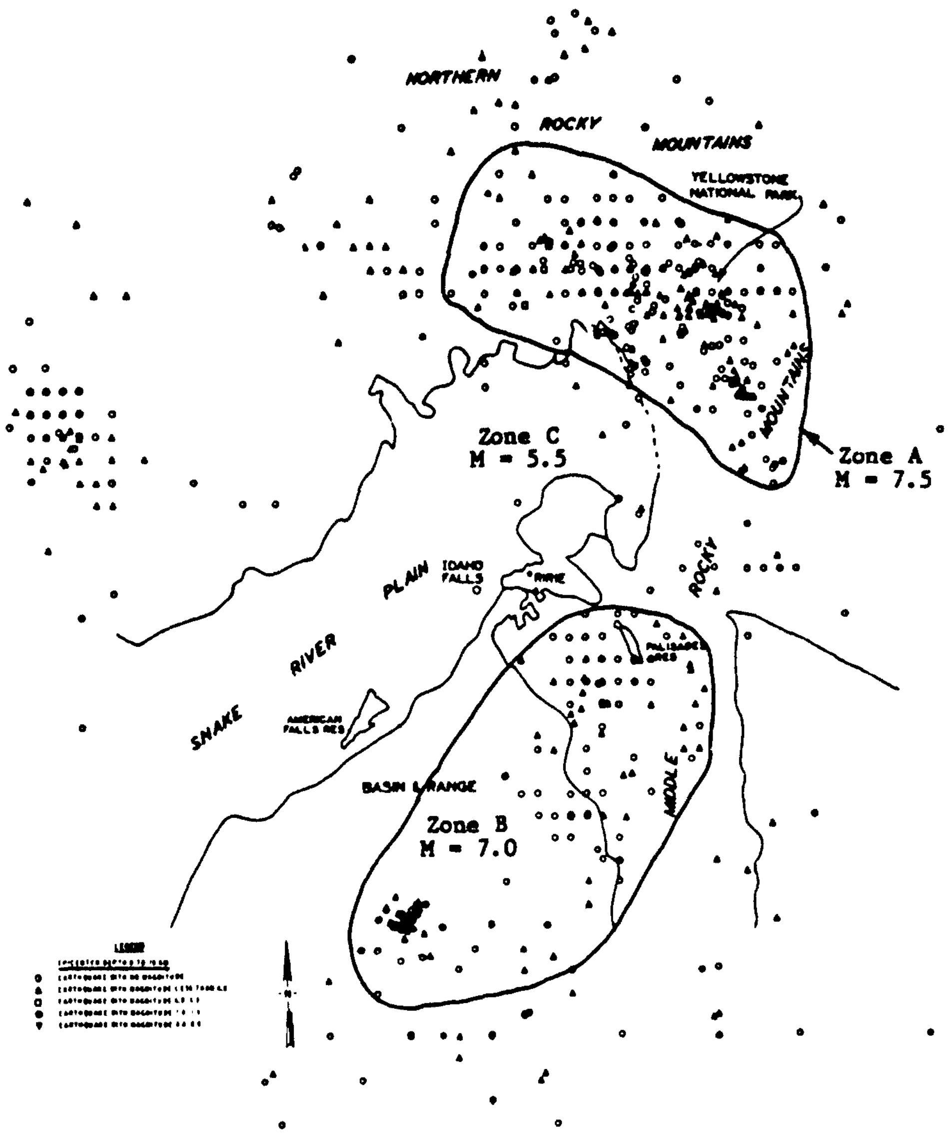

Figure 39. Seismic zonation map (Note that the zones are not to be interpreted as being rigid or fixed seismic zones.)

101. The seismicity in Zone B includes earthquake events occurring in a broad band extending southwest of the Snake River graben to the Utah-Idaho border. The area of greatest seismic activity occurs at the southwest terminus of the zone and includes both the 1962 Cache Valley and 1975 Malad City events (see Table 2). Generally, the seismicity becomes less pronounced from this area toward the northeast and toward the north at the damsite. This large area of rather diverse seismicity, particularly with respect to earthquake size, is considered to be a meaningful and conservative seismotectonic entity because of the generally limited information on capable faults and limited historical earthquake coverage throughout this area. It is apparent that a less conservative approach to regional zonation would be to subdivide Zone B into two zones, one of which would include the general area of the Malad City and Cache Valley earthquakes along the Utah-Idaho border and the other zone including the area of rather low level seismicity to the west of the Snake River graben and south of the site. However, such a subdivision would imply that there was sufficient evidence to conclude that the Cache Valley and Malad City type events could not occur any closer to the site than this general area of the Utah-Idaho border. Furthermore, there would be the implication that the Snake River graben is conclusively not a source of earthquakes. Both implications may be too uncertain, therefore, for such a subdivision, and conservatism requires that these two subareas be included in the same zone. This conservatism may be lessened somewhat by not requiring the maximum earthquake for this zone to "float" closer to the site than the radius of the near field for this event.

Recurrence

102. Recurrence curves were constructed for Zones A and B. These curves (Figure 40) demonstrate the relation between an event of a given size and time. Recurrence curves provide the following information: (a) the curves show the frequency of occurrence of a particular event;

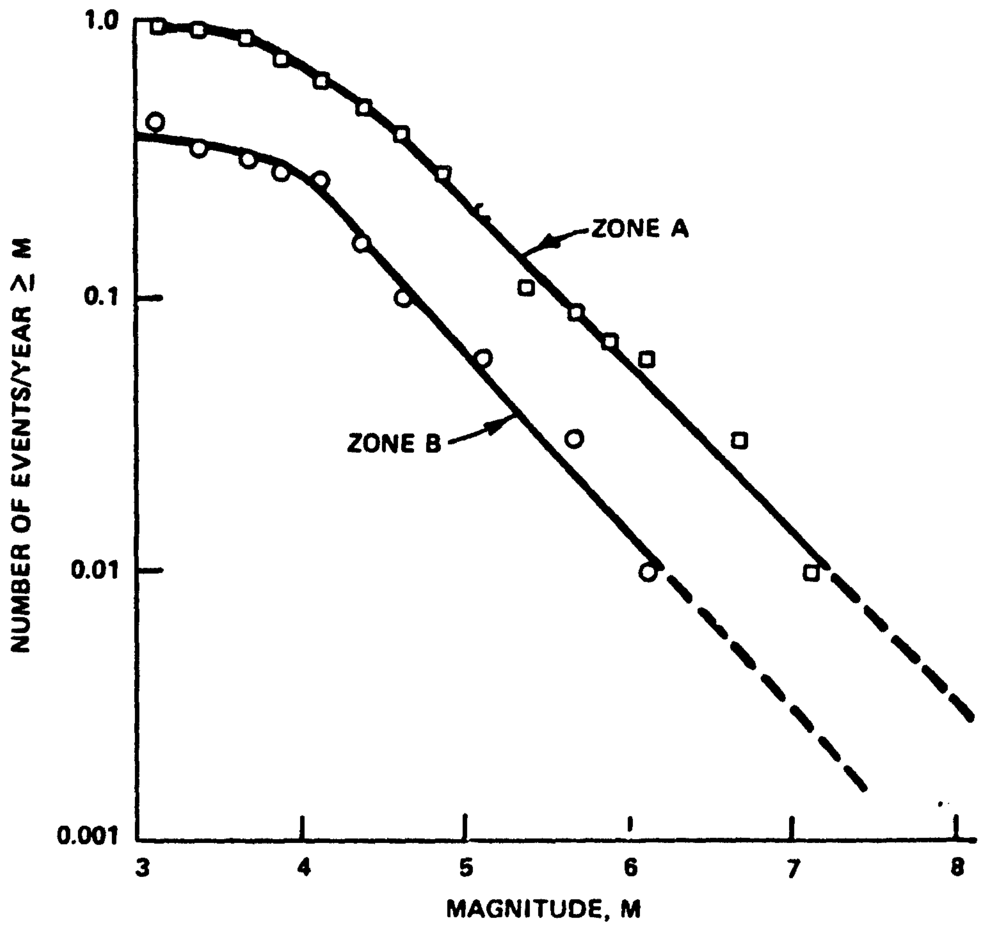

Figure 40. Recurrence curves for seismic Zones A and B

(b) the relative smoothness of the curve is indicative of the sufficiency and reliability of the data; (c) the curves provide a basis for comparing two or more zones; (d) in conjunction with geologic and structural data, the curves may be used to identify maximum earthquakes; and (e) the curves form the basis for statistical evaluation.

103. The recurrence curves are both relatively smooth indicating that the data base is sufficiently large with respect to the number of events and number of years considered and that reliable information may be obtained from them. However, there is no indication of a steepening of the slopes toward higher magnitude values; such a steepening would more readily lend itself to the determination of maximum earthquakes. In the absence of steepening and without geological evidence of active or capable faults, the determination of maximum earthquakes must be somewhat arbitrary.

104. The recurrence curves developed by Creensfelder (1976) for ISB and the Basin and Range Province in Idaho are shown in Figures 41 and 42, respectively. Note that these curves take area into account. Cenerally, Greensfelder's curves suggest that the Basin and Range Province has a somewhat lower level of seismicity than the overall ISB and that the slopes of the two curves are slightly different. The comparison of Greensfelder's curves with those developed in this study reveals that the curve for Zone A exhibits a higher level of seismicity than that of the overall ISB and that the seismicity level for Zone B is similar to the level in the ISB.

105. A tabulation of earthquake magnitude versus return period for 10, 100, and 100 yr is given below for both seismic zones:

Return Period, yr	Earthquake Magnitude Zone A	Zone B
10	5.6	4.8
100	7.3	6.2
1000	8.8	7.8

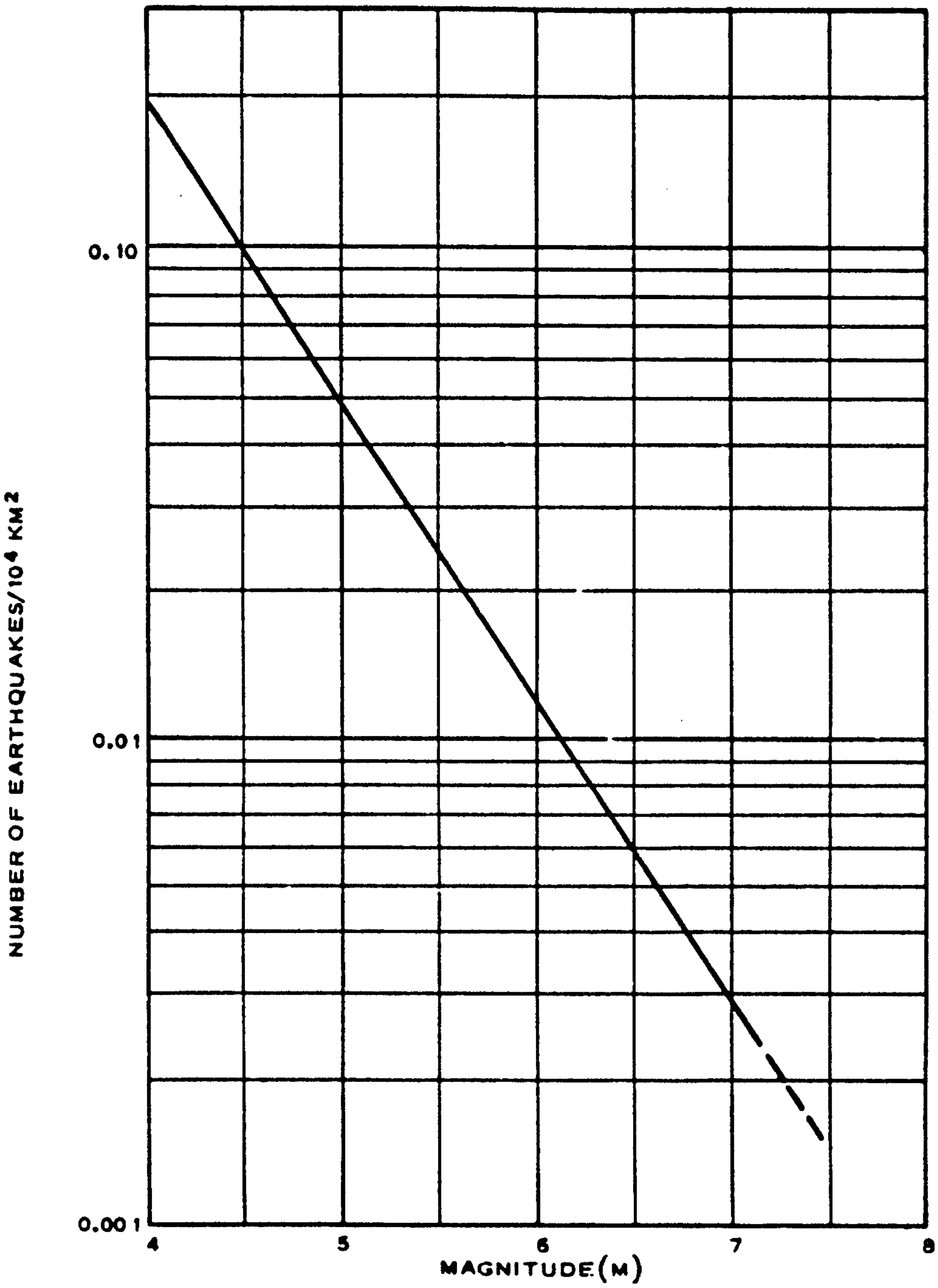

Figure 41. Recurrence curves for ISB (Greensfelder, 1976)

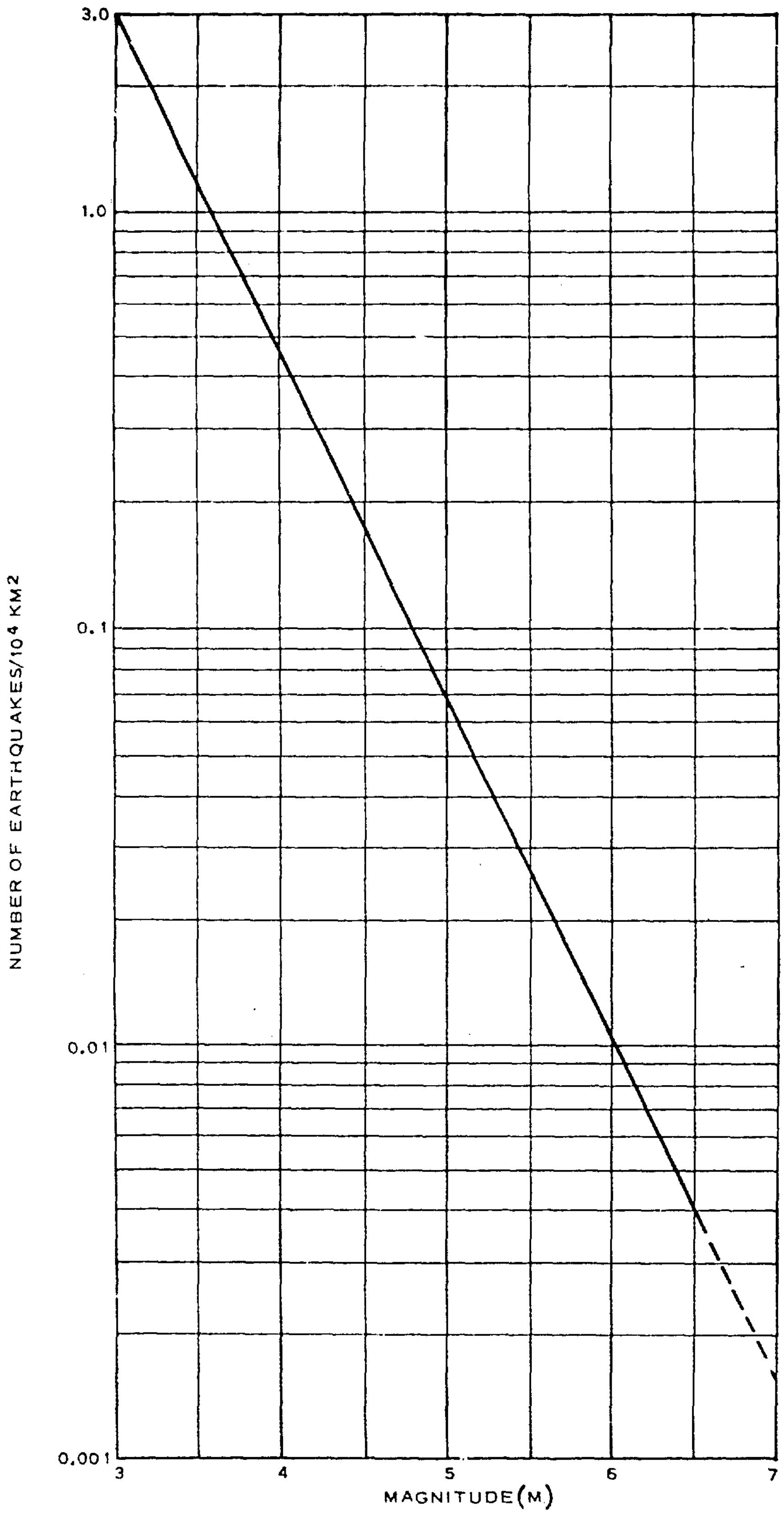

Figure 42. Recurrence curves for the Basin and Range Province (Greensfelder, 1976)

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This tabulation and Figure 40 indicate that seismic activity in Zone A is considerably higher than that in Zone B. For both zones, the data for 1000 yr have been obtained by extrapolation. It is possible, however, that the curves steepen sharply and turn down. Thus, the straight-line extrapolation of these curves to higher return periods (lower recurrence) is conservative.

Maximum Earthquakes

106. The maximum earthquake (ME) is the severest earthquake that is believed to be possible at the site on the basis of geological and seismological evidence (Office, Chief of Engineers, 1977). Maximum earthquakes may be determined for faults which are believed to be capable and for zones of earthquake activity. Previous parts of this report have shown that no conclusive evidence exists for the occurrence of capable faults, although there is some degree of uncertainty. Therefore, maximum earthquakes were determined for each earthquake zone (A, B, and C) primarily on the basis of the historical seismic record and consideration of the uncertainty pertaining to capable faults. The recurrence curves (Figure 40) were used to establish a lower magnitude limit. The lower limit was taken as that magnitude event which could be expected to occur during 100 yr. This time period is approximately equal to the period of record and somewhat larger than the expected project life. These magnitude values are given in the tabulation above. The maximum earthquakes, shown below, were determined by increasing the 100-yr magnitude event in Zone A from 7.3 to 7.5 and the Zone B event from 6.2 to 7.0:

Zone A   M = 7.5

Zone B   M = 7.0

107. These values are believed to be reasonable, conservative, and to reflect the uncertainty which exists with respect to the earthquake record and faulting. These maximum earthquakes may occur anywhere in their respective zones with the exception that the Zone B earthquake may occur no closer to the site than the radius of the near field for that earthquake as defined by Krinitzsky and Chang (1977).

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108. The maximum earthquake is likely to occur near the site on the Rexburg Bench or on the Snake River Plain; Zone C must also be considered. Greensfelder (1976) considers that the maximum earthquake for this area would be a magnitude 5.0 event. The size of this event was based upon the seismicity of other volcanic terranes such as Iceland. It is apparent that insufficient seismic data is available for the Ririe Dam area to make a definitive determination. However, it seems reasonable and conservative to consider the local ME to be an event somewhat larger than magnitude 5.0; therefore, the local ME is arbitrarily defined as a magnitude 5.5 event.

109. Thus, the three events (ME's) that must be considered in the selection of design earthquakes are:

Zone A $M = 7.5$

Zone B $M = 7.0$

Zone C $M = 5.5$

110. The design earthquake will be the event that yields the highest intensity and concomitant ground motions after attenuation to the site. These earthquake magnitudes are considered to be conservative yet reasonable in terms of the structural and tectonic setting of the area (Slemmons, 1976).

Reservoir-Induced Seismicity

111. In certain geologic and seismological environments, the filling of large reservoirs may induce earthquakes. Generally, only reservoirs having depths exceeding 100 m in height and impounding over 1,000,000 acre-ft of water are considered likely to induce earthquakes (Johnson, Krinitzsky, and Dixon, 1977). The consideration of induced seismicity is important because this factor determines the location of the local earthquake; that is, if the reservoir is considered likely to induce earthquakes, the induced earthquake event is postulated to occur at the reservoir and to produce near-field conditions.

112. The determination of susceptibility for inducing earthquakes is based upon three elements: (a) size of dam and reservoir, (b) capable

faults at site, and (c) the history of induced seismicity at other sites in area. The significance of these three elements at Ririe Dam is given below.

Dam and reservoir size

113. Ririe Dam is 251 ft high and the impoundment is approximately 100,000 acre-ft, but these dimensions are smaller than those in any case where reservoir-induced seismicity has been described.

Capable faults

114. Although the faults in the vicinity of the site are relatively young, they are not judged to be capable or active. The absence of capable or active faulting diminishes the prospects of induced seismicity.

History of induced seismicity

115. If the review of the historical seismicity produced evidence that similarly sized, nearby reservoirs have induced earthquakes, there would be a strong possibility that Ririe Lake could also induce earthquakes. The nearest large reservoir to Ririe is Palisades Reservoir. The dam there is 270 ft high and the impoundment is 1,402,000 acre-ft. Schleicher (1975) has studied the relations between water level at Palisades Reservoir and the occurrence of numerous small earthquakes whose center of activity lies in the Caribou Range approximately 10-20 km to the west. These earthquakes lie in the northern one-half of Zone B. Schleicher's data included approximately 120 events detected between 1960 and 1969. No data were available for prefilling conditions prior to filling of the reservoir in 1956. Also, there is only minor microseismic monitoring data; this area of the Caribou Range was monitored for a month in 1966 and a few days in 1969. Such short periods of time are usually insufficient to establish meaningful relationships (Patrick, 1977). Schleicher's (1975) study revealed, however, a fairly strong apparent correlation between water level in the reservoir and the number of earthquakes; generally, the greatest occurrence of events coincided with extreme high or low pool elevation. Schleicher concluded that the reservoir may have triggered movement on the faults that bound the Snake River graben (see Figure 35).

116. The supposition that Palisades Reservoir has induced earthquakes is beset with difficulties, primarily with respect to the data base and the locations of the suspected induced events. As previously mentioned, the absence of prefilling data poses serious interpretative problems. The locations of the suspected induced events seem exceedingly distant from the reservoir to be related to water level changes and movement on the boundary faults at the dam. It would appear that the evidence supporting induced seismicity at Palisades Reservoir is nonconclusive.

117. American Falls Reservoir, located on the Snake River plain approximately 125 km southwest of Ririe Dam, is in an extremely aseismic area; no earthquakes have been reported within 50 km of the dam. The height of the dam is 94 ft and the impoundment is 1,700,000 acre-ft. Blackfoot Reservoir (height, 49 ft; capacity, 413,000 acre-ft) and Grays Lake (height, 12 ft; capacity, 40,000 acre-ft) are located south of Ririe, and neither have induced earthquakes.

118. The significance of whether Palisades Reservoir has induced seismicity may not be very meaningful, since this dam is situated in an area of considerably different geological and seismological character than that of Ririe.

119. The absence of seismicity at American Falls, the small size of Ririe, the apparent absence of seismicity during the filling of Ririe, the absence of capable faults, and the overall lack of seismicity in the reservoir area indicate that induced seismicity is not to be expected at Ririe.

120. Thus, the local Zone C as well as the Zone B event earthquake should be located no closer to the dam than the limit of the near fields for these events.

Focal Depth and Mechanisms

121. Smith and Sbar (1974) have presented information on the focal depths, mechanisms, and tectonic association of earthquakes in the Intermountain Seismic Belt. Generally, most of the earthquakes in this

area occur at focal depths less than 20 km and many occur at less than 10 km. Mechanisms of faulting determined from fault plane solutions are known for some earthquake events in limited areas.

122. In the Hebgen Lake-Yellowstone National Park area (Zone A), fault plane solutions for the 1959 Hebgen Lake earthquake indicated dip slip movement, which was in accord with observed surface displacements. The mechanism for the 1964 event in the area was strike slip. Fault plane solutions have been made for aftershocks of the Cache Valley earthquake along the Utah-Idaho border (Zone B). These data indicate normal faulting with focal depths of 3 to 16 km.

PART V: DESIGN EARTHQUAKES

General

123. Having established the maximum earthquakes and their locations within their respective zones, the next step in the analysis is the determination of the expected ground motions (particle acceleration, velocity, and displacement) at the site caused by these maximum earthquakes. The design earthquake will be that which produces the largest motions at the site. Generally, site ground motions can be determined by two methods; one method involves empirical relations between magnitude, distance from earthquake, and acceleration (Schnabel and Seed, 1973). This methodology is widely used in the western United States, particularly in California. The second method involves the attenuation of intensity and the correlation of ground motion with the attenuated intensity (Krinitzsky and Chang, 1977). Both methods will be given below.

Attenuation

124. The attenuation of seismic energy from a source area to a given point of interest is a complex determination. The attenuation that occurs is a function of the source mechanisms (type of faulting, magnitude, frequency content, etc.), nature of the path (structure, lithology), and the geology of the site. Ordinarily, there is insufficient information available concerning these variables to precisely define the amount of attenuation that will occur. In the absence of site-specific information, attenuation is based upon empirical data relating intensity to distance for the general region. Empirical curves, such as those given in Krinitzsky and Chang (1977) for the western, central, and eastern United States, may be used; presumably the curves for western United States would be applicable for the Ririe, Idaho area.

125. The attenuation curves for the western United States are shown in Figure 43. These curves are based upon MM intensity. The

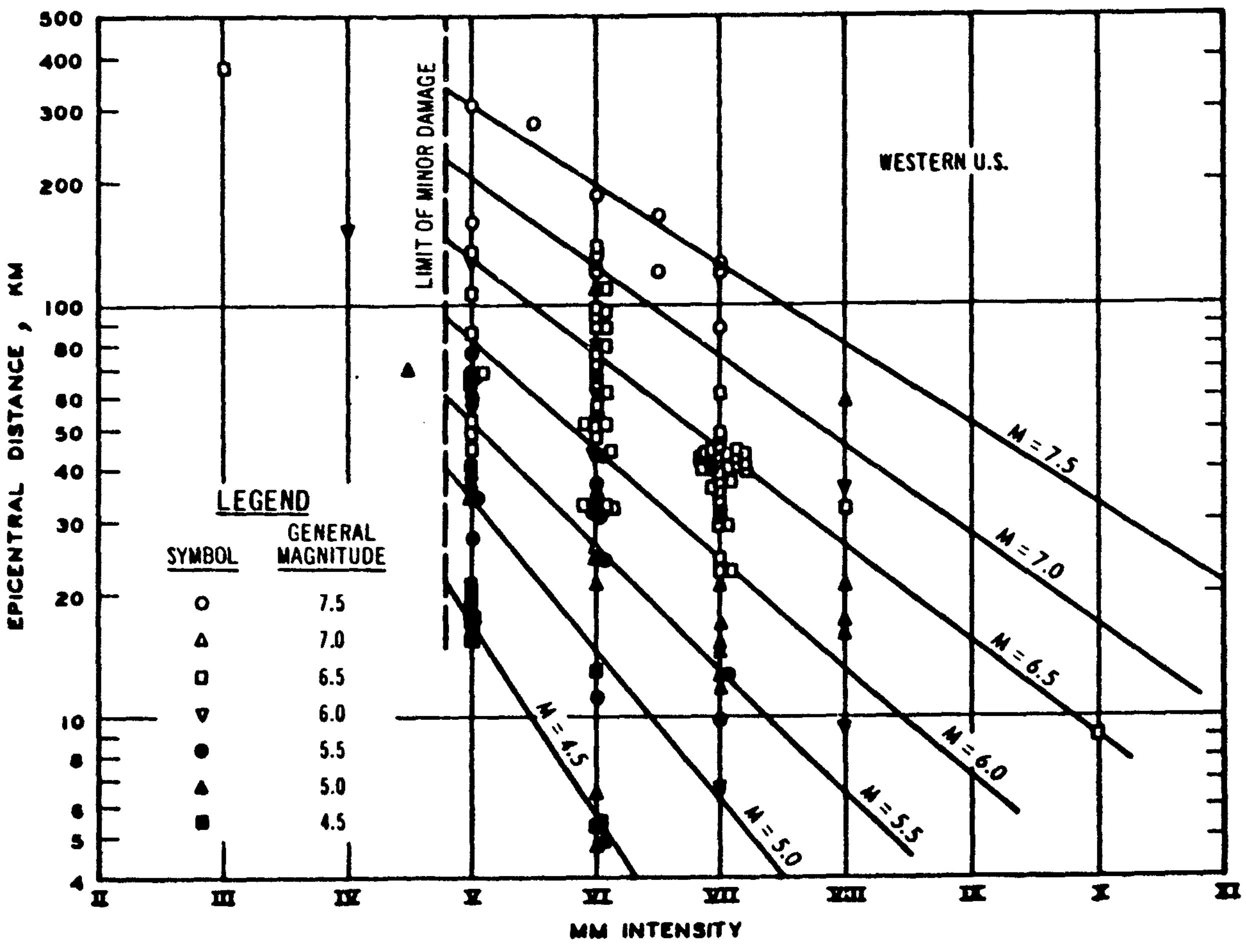

Figure 43. Attenuation curves for the western U. S. (Krinitzsky and Chang, 1977)

equivalent epicentral intensity and radius of near field for given earthquake magnitudes are given below (Krinitzsky and Chang, 1977):

Richter Magnitude (M)	MM Maximum Intensity (I_o)	Radius of Near Field (km)
8.0	XI	--
7.5	XI	45
7.0	X	40
6.5	IX	35
6.0	XIII	25
5.5	VII	15

126. The applicability of the western United States attenuation curves was verified by studies of attenuation exhibited by the Hebgen Lake, Cache Valley, and Malad City events. The respective isoseismal maps for these three events are shown in Figures 44, 45, and 46. Intensity information was extracted from each isoseismal map along a line extending from the epicenter of the particular event to Ririe. Figure 47 is a plot of these intensities versus distance for the three events.

127. Table 3 shows the comparison between attenuations derived from the isoseismal maps and attenuations determined from curves for the

Table 3

Comparison of Intensity Values Derived from Isoseismal Maps with Values Taken from Attenuation Curves for the Western United States

Event	Distance km	MM Intensity	
		Isoseismal Map	Western U. S. Curves
Hebgen Lake,	25	Near Field	Near Field
M = 7.1, I_o = X	50	VII - VIII	VII - VIII
Near Field* = 40 km	75	VI - VII	VII
	100	VI - VII	VI - VII
	175	V - VI	V

(Continued)

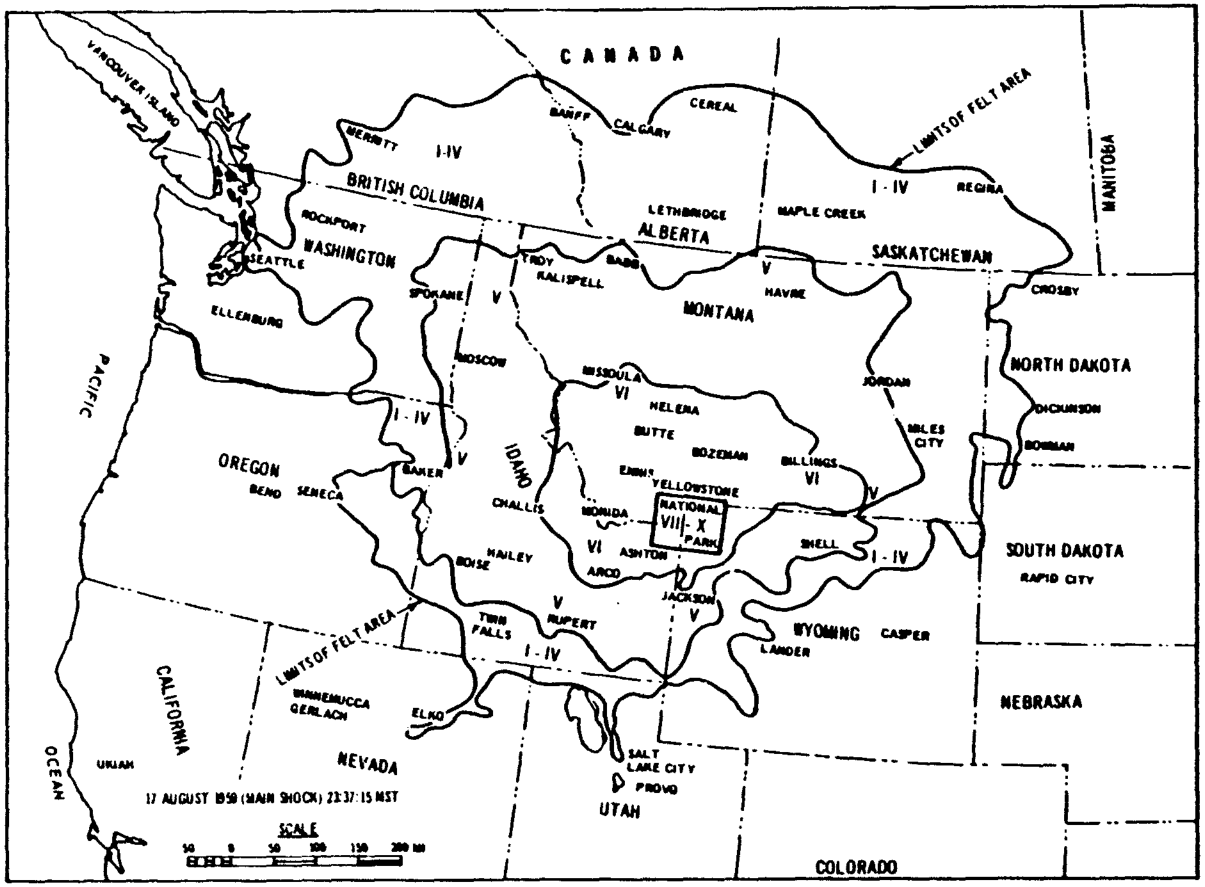

Figure 44. Isoseismal map of Hebgen Lake earthquake

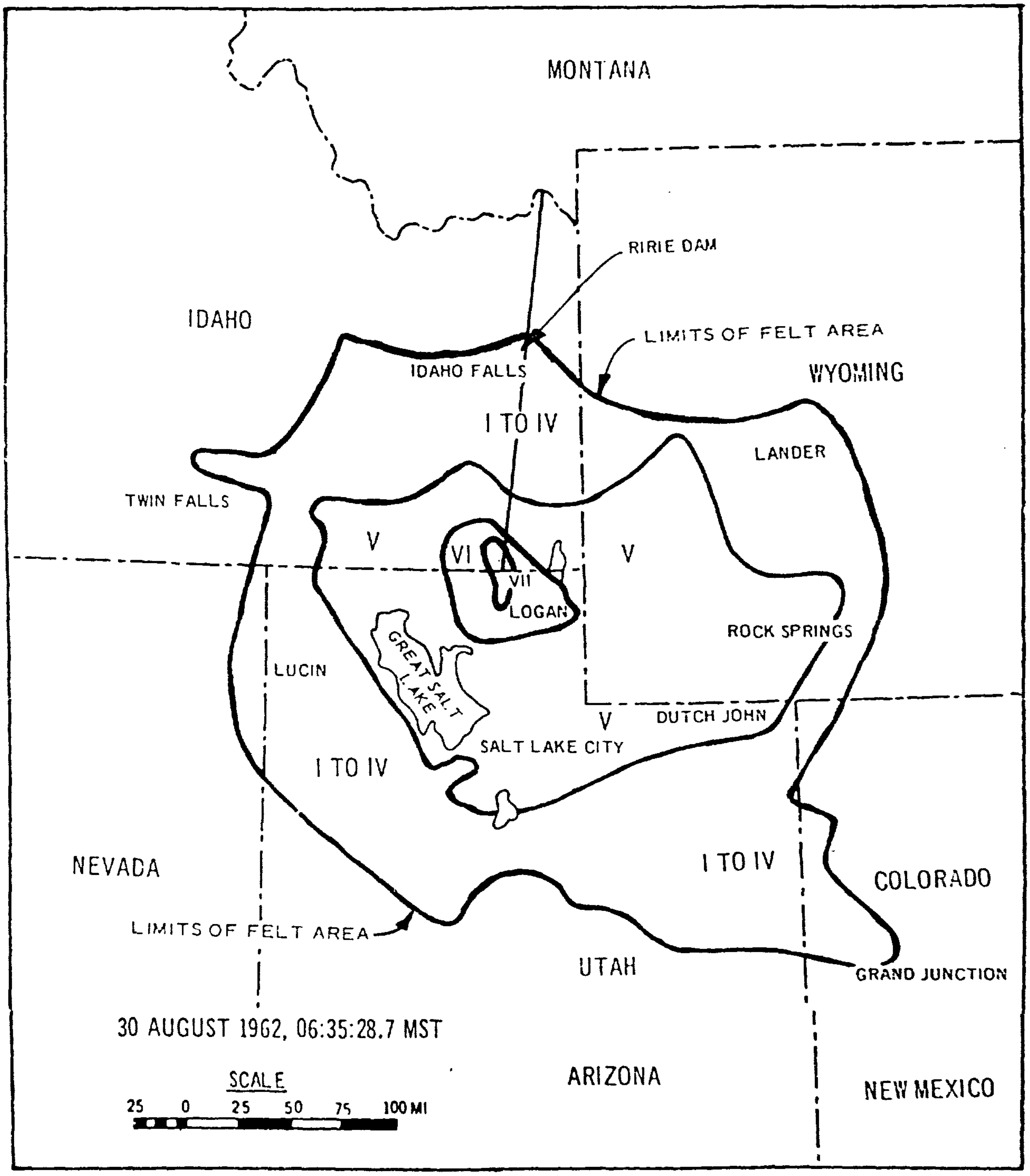

Figure 45. Isoseismal map of Cache Valley earthquake

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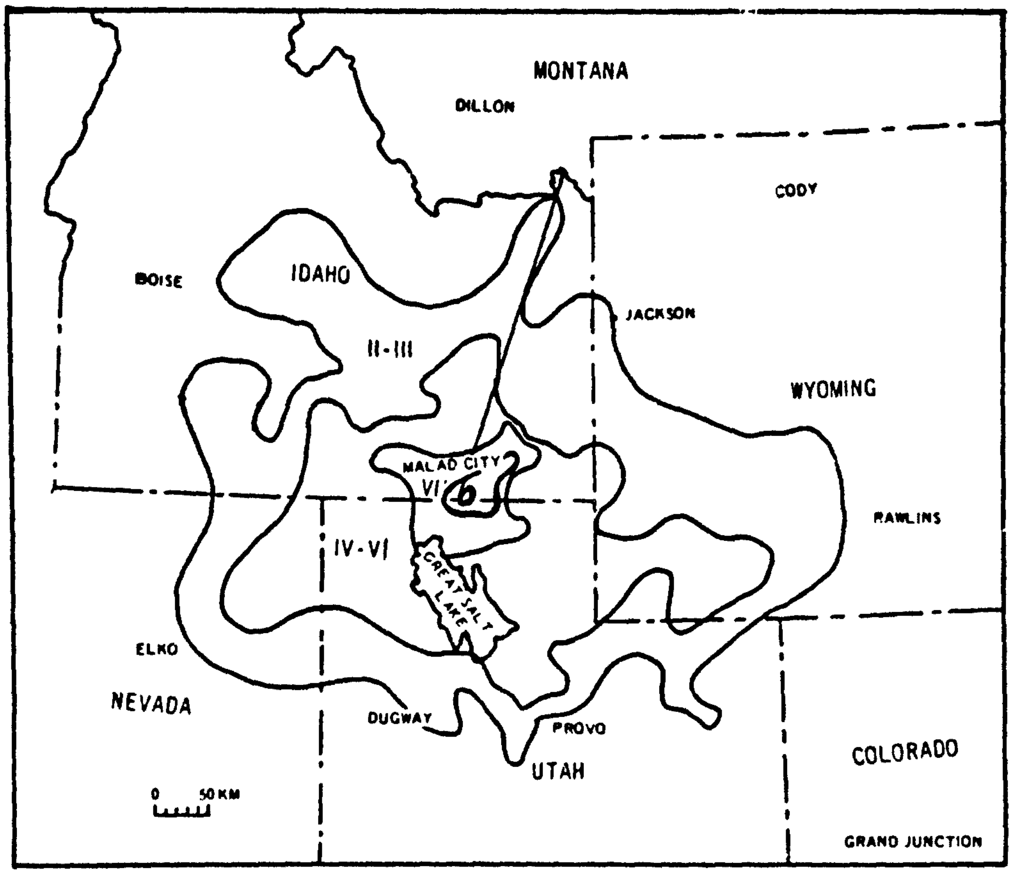

Figure 46. Isoseismal map of Malad City earthquake

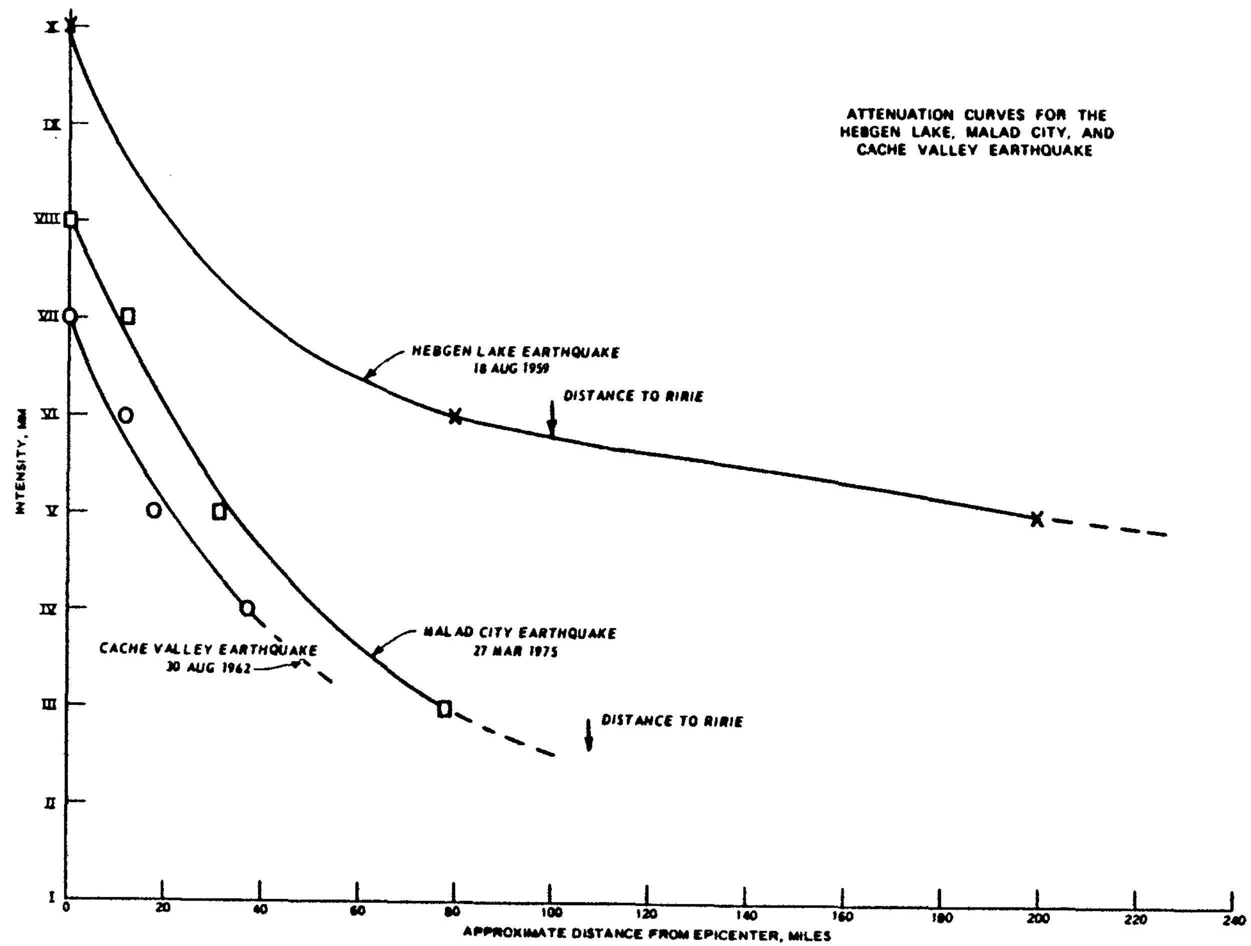

Figure 47. Intensities versus distance of Hebgen Lake, Cache Valley, and Malad City earthquakes

Table 3 (Concluded)

Event	Distance km	MM Intensity: Isoseismal Map	MM Intensity: Western U. S. Curves
Cache Valley	25	V - VI	VI
$M = 5.7$, I_o = VII	50	IV - V	V
Near Field* = 15 km	75	III - IV	V
	100	Not felt	--
	175	Not felt	--
Malad City	25	VI - VII	VII
$M = 6.1$, I_o = VIII,	50	V	VI
Near Field* = 25 km	75	IV - V	V
	100	III - IV	V
	175	Not felt	--

western United States. The examination of the table reveals that the attenuation of seismic energy for these three earthquakes was typical for the western United States and indicates that the empirical attenuation curves for the western United States (Figure 43) are appropriate for the Ririe area.

128. The ME's epicentral intensities, site intensities, and distances to the site are given below for each zone:

Zone	ME(M)	Epicentral Intensity (MM)	Distance from Zone to Ririe (km)	Field	Site Intensity (MM)
A	7.5	XI	105	Far	VII-VIII
B	7.0	X	40	Far	VIII-IX
C	5.5	VII	15	Far	VI-VII

129. The field conditions for all three events are considered to be far field. Note that the limits of Zone B are approximately 40 km from the site. The Zone B event was placed at the near-field radius because there was no compelling reason to suspect activity at the site. Thus, in the absence of active or capable faults and induced seismicity at the site, the events should be located no closer to the site than the near-field radius.

Earthquake Ground Motions

130. Bedrock accelerations for the state of Idaho have been determined by Greensfelder (1976) who believed that earthquakes would occur on the mapped young faults. Using recurrence data he determined himself, recurrence data of Smith and Sbar (1974), western United States attenuation rates, and probability analysis, Greensfelder determined the maximum probable magnitudes and accelerations for the tectonic provinces of Idaho. Greensfelder's study did not involve earthquakes originating in the Yellowstone National Park (Zone A of this study).

131. Figure 48 is a map showing Greensfelder's (1976) maximum probable rock accelerations for the Ririe area. These acceleration values shown have a probability of exceeding of 10^{-4}/yr. The maximum earthquake was considered to be magnitude 6.5 in nonfaulted areas and magnitude 7.0 along major faults. Greensfelder assumed that the faults bounding the Snake River graben were capable of producing earthquakes. Such an interpretation resulted in the high acceleration values at Ririe of approximately 45 percent g and 75 percent g on the faults. The shaded area southeast of Ririe in the Caribou Range could expect a randomly distributed event producing accelerations of approximately 75 percent g. The shaded area is the region of suggested reservoir-induced seismicity.

132. Greensfelder's (1976) acceleration values are not considered to be applicable to Ririe Dam mainly because it is not believed that either of the faults bounding the Snake River graben is active or capable. Another reason pertains to Greensfelder's magnitude 6.5 maximum earthquake. Such a value seems too low when one considers that the Malad City event was magnitude 6.1. Recall from paragraph 105 that for Zone B a magnitude 6.2 event exhibited a return period of approximately 100 yr. Thus, even though the mapped acceleration values for the magnitude 6.5 event exhibit a low probability value (10^{-4}/yr), they may not, in fact, be particularly conservative.

133. Greensfelder's (1976) procedures also do not adequately distinguish between the near and far fields. The near-field radius for

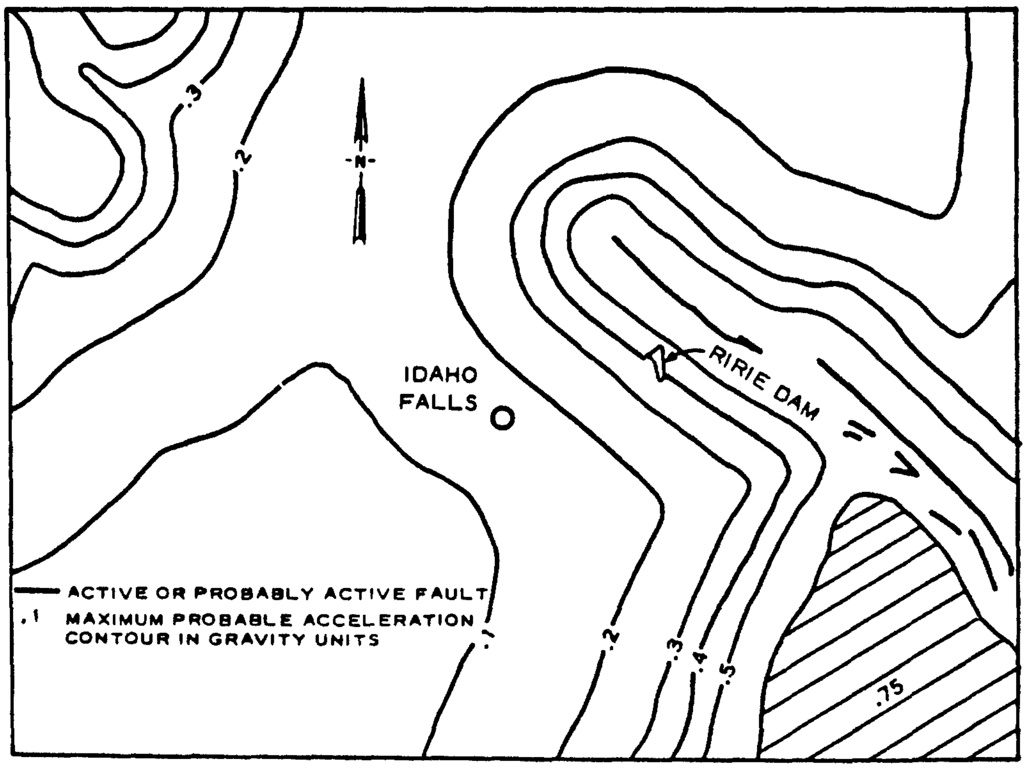

Figure 48. Maximum probable rock acceleration for the Ririe Dam area (Greensfelder, 1976)

a magnitude 7.0 event on the Grand Valley fault would be 40 km. The near field would then include the damsite at Ririe, and the ground motions could easily be higher than the 45 percent g shown on Greensfelder's map.

134. The following procedures for determining ground motions (acceleration, velocity, and displacement) are empirical in nature and are based upon the expected site intensity from a maximum earthquake originating in a particular zone or source and upon tabulated relations between intensity and ground motion. Charts relating intensity and ground motions have been developed by Krinitzsky and Chang (1977). Figures 49, 50, and 51 show the relations between intensity and acceleration, velocity, and displacement, respectively. Current practice at the U. S. Army Engineer Waterways Experiment Station (WES) requires that the line denoting 80 percent of observed data be used.

135. The tabulated values for peak, horizontal ground motions at the site for events in the respective earthquake zones are given below:

Zone	Site Intensity (MM)	Acceleration (g)	Velocity (cm/sec)	Displacement (cm)
A	VII - VIII	0.22	32	20
B	VIII - IX	0.28	40	23
C	VI - VII	0.16	25	15

136. The relations between intensity and duration of strong motion (bracketed acceleration $\geq$ 0.05 g) are shown in Figure 52. The value for duration will be approximately 10 sec, specified for hard rock under the embankment.

137. The determination of peak ground motions may also be derived using relations between magnitude, distance, and acceleration or velocity. Schnabel and Seed (1973) and Nuttli (1979) methods were also used to determine ground motions and are given below. The Schnabel and Seed (1973) method gives average values of maximum peak acceleration and the Nuttli (1979) technique involves determination of maximum sustained ground acceleration and velocity and their equivalent peak motions:

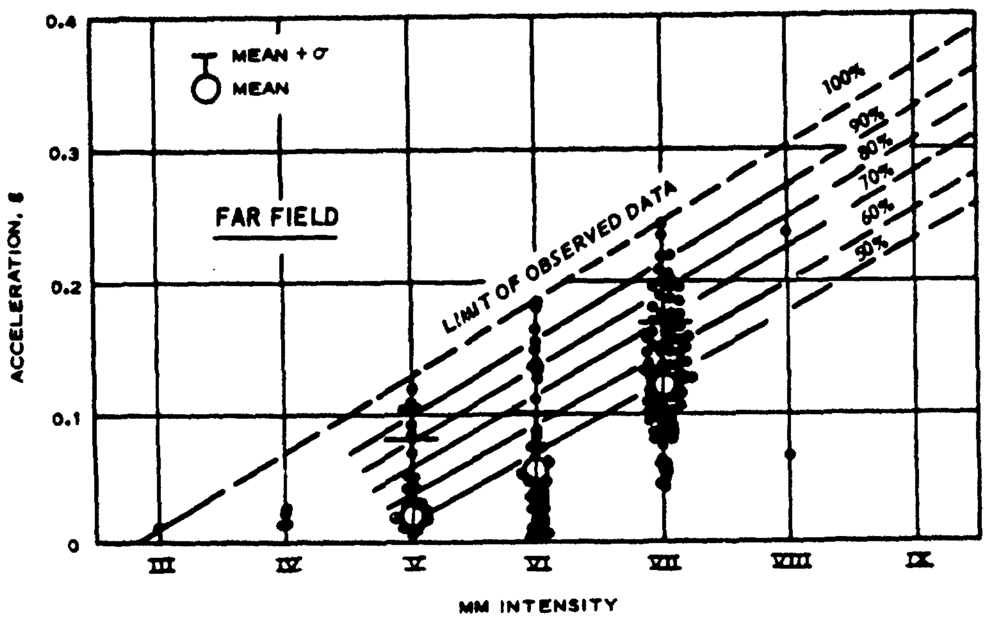

Figure 49. Acceleration versus MM intensity in the far field (10 percent increments between the mean (50 percent) and the limit of observed data (100 percent) (Krinitzsky and Chang, 1977))

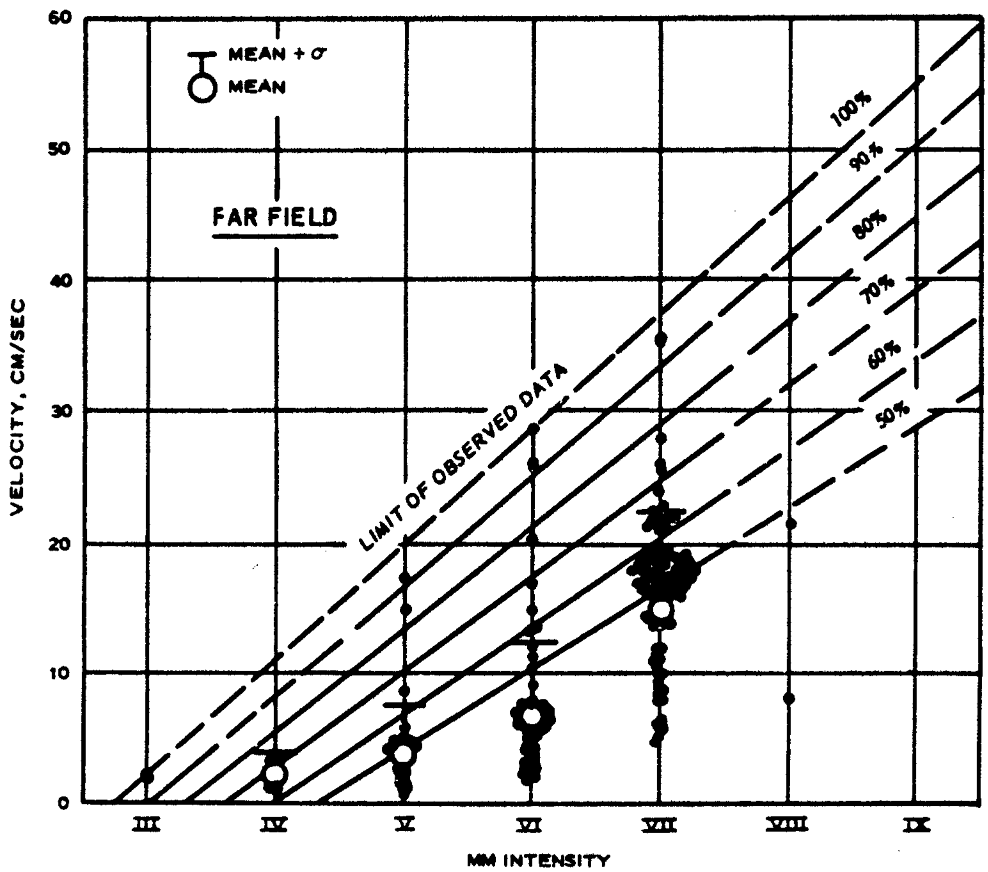

Figure 50. Velocity versus MM intensity in the far field (10 percent increments between the mean (50 percent) and the limit of observed data (100 percent)(Krinitzsky and Chang, 1977))

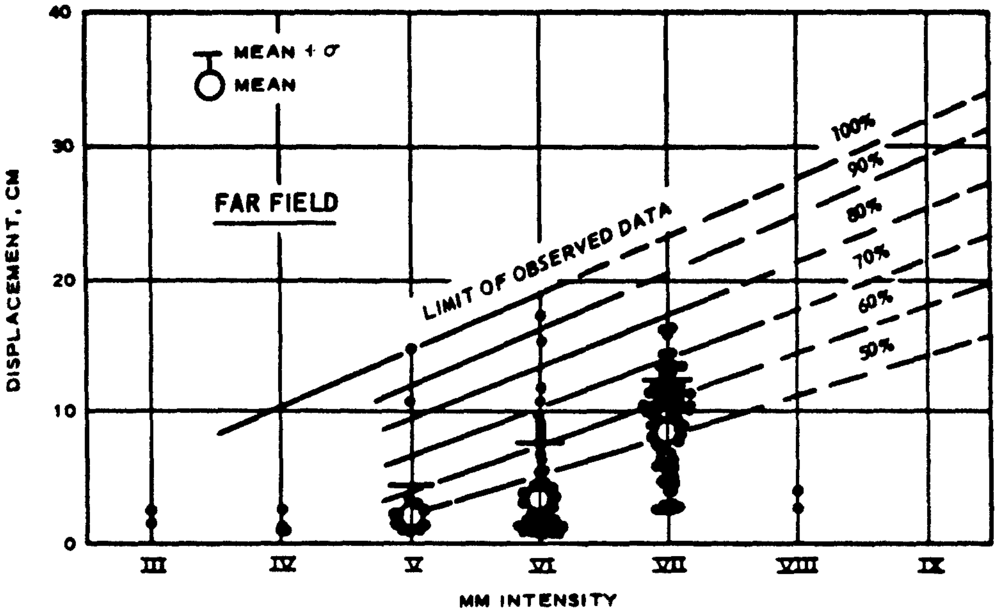

Figure 51. Displacement versus MM intensity in the far field (10 percent increments between the mean (50 percent) and the limit of observed data (100 percent)(Krinitzsky and Chang, 1977))

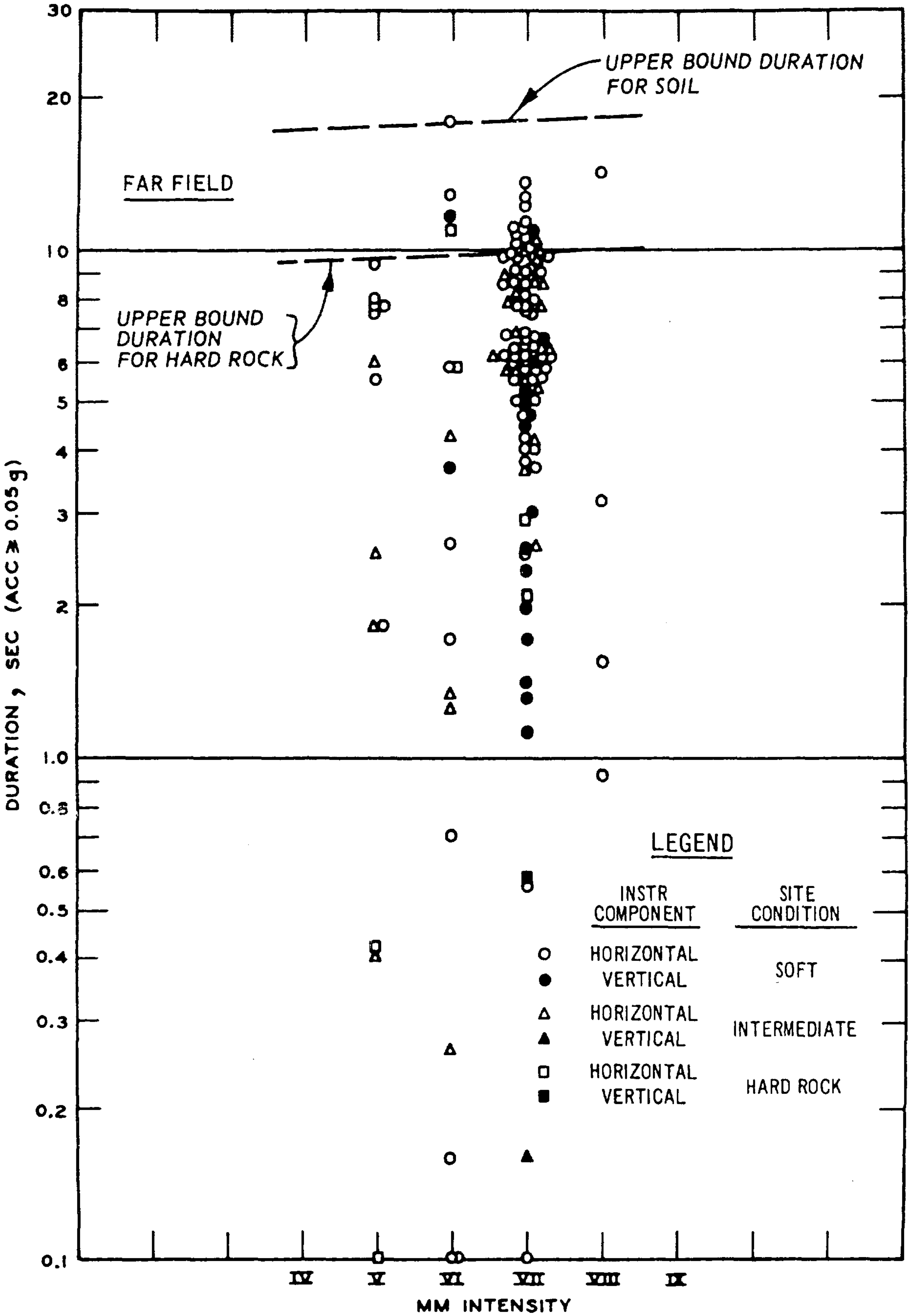

Figure 52. Duration versus MM intensity in the far field (Krinitzsky and Chang, 1977)

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Zone	Schnabel and Seed (1973) Peak acceleration (g)
A	0.07
B	0.20
C	0.19

Zone	Nuttli (1979) Peak acceleration (g)	Peak Velocity (cm/sec)
A	0.09	18
B	0.21	26
C	0.13	4

138. The ground motions shown above may be compared with those shown in paragraph 135 which were determined by the Krinitzsky and Chang (1977) method. The latter method is seen to give somewhat higher values since motions were obtained using 80 percent of observed data. The motions determined by the Krinitzsky and Chang method appear reasonable and conservative and will be used for the determination of design earthquakes in the following section.

Design and Operating Basis Earthquakes

139. The design basis earthquake, the event through which the dam must maintain its functional integrity, is the Zone B earthquake. These motions are free field. A recapitulation of the data for this event is given below:

Zone	Magnitude	I_o (MM)	Distance to Ririe, km	I_{site} (MM)	Accel. g's	Velocity cm/sec	Displacement cm
B	7.0	X	40	VII-IX	0.28	40	23

(Duration on hard rock = 10 sec)

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140. The operating basis earthquake, the event through which the dam must maintain an operational status, would be the Zone C event below (Again, these motions are free field.):

Zone	Magnitude	I_o (MM)	Distance to Ririe, km	I_{site} (MM)	Accel. g's	Velocity cm/sec	Displacement cm
C	5.5	VII	15	VI-VII	0.16	25	15

(Duration on hard rock = 10 sec)

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PART VI: SUMMARY AND CONCLUSIONS

141. The evaluation of site geology based upon field observations, reexamination of boring logs, core drilling, aerial photography, and structural contour and isopach mapping resulted in the conclusion that subsurface offsets under the embankment were interpreted as landslide and topography-related rather than as faults. The evidence for the nontectonic origin of the offsets includes the following: (a) extensive modern landslides along Willow Creek, (b) topographic evidence for landslide on left abutment prior to the alluviation of Willow Creek, (c) the inability to reconstruct rational "prefault" conditions, (d) lack of sheared or gouged zones, and (e) the significant amount of topographic variation on the marker horizon surfaces.

142. Reservoir-induced seismicity is not considered to be a seismic hazard at Ririe Dam due to the absence of active or capable faults in the site, the small size of the dam and lake, and the absence of well-documented evidence for induced seismicity at other, regional reservoirs. Regionally, the USGS has preliminarily identified six faults within 200 km of the site that exhibit historic or Holocene age movement. Two occur in the Hebgen Lake area and nearby portions of southwestern Montana (adjacent to Yellowstone National Park); one occurs on the Utah-Idaho border. These three faults are in areas having high levels of seismicity. Two fault systems occur on the Snake River Plain and are not associated with high seismicity. The Grand Valley fault bordering the Snake River graben to the east of the site is considered to be Holocene in age by the USGS; however, there is no compelling evidence for this age.

143. The examination of the regional historic seismicity and the integration of information from fault studies revealed that the region could be subdivided into three seismic zones. One zone is the Yellowstone National Park area (Zone A); the second zone is a broad area of southeastern Idaho directly south of the site (Zone B); and the third zone included the site itself and the adjacent Snake River Plain

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(Zone C). Recurrence curves were plotted for Zones A and B; recurrence data integrated with fault information were used to identify maximum earthquakes in each zone. These maximum earthquakes for each zone are: Zone A, magnitude 7.5; Zone B, magnitude 7.0; and Zone C, magnitude 5.5. The Zone A and B events are believed to have a return period of approximately 500 yr.

144. Ground motions from these zones were attenuated to the site using western United States attenuation data. The resulting ground motions for each zone are all far field. The design basis earthquake, a Zone B event, would produce the following peak ground motions at the site: acceleration 0.28 g; velocity 40 cm/sec; and displacement, 23 cm. The duration of strong motion (bracketed acceleration $\geq$ 0.05 g) on hard rock under the dam is estimated to be 10 sec.

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APPENDIX A

BORING LOGS

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Hole No. DH 251

DRILLING LOG	DIVISION	INSTALLATION	SHEET 1 OF 1 SHEETS

1. PROJECT: Earthquake Hazard Study
2. LOCATION (Coordinates or Station): Ririe Dam, Ririe, Idaho
3. DRILLING AGENCY: Corps of Engineers, Walla Walla District
4. HOLE NO. (As shown on drawing title and file number): DH 251
5. NAME OF DRILLER: Don Keys
6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN: 58.0 ft
8. DEPTH DRILLED INTO ROCK: 39.7 ft
9. TOTAL DEPTH OF HOLE: 97.7 ft
10. SIZE AND TYPE OF BIT: NX
11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MSL
12. MANUFACTURER'S DESIGNATION OF DRILL:
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED | UNDISTURBED
14. TOTAL NUMBER CORE BOXES: 1
15. ELEVATION GROUND WATER: -----
16. DATE HOLE: STARTED 24 July 1978; COMPLETED 29 July 1978
17. ELEVATION TOP OF HOLE: 4962.5 ft
18. TOTAL CORE RECOVERY FOR BORING: 84 %
19. SIGNATURE OF INSPECTOR:

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
4962.5			Random Fill-clay to boulder size			
	10					
			Alluvium --silt, sand, gravel, boulders			Cemented hole
	20		Cl.-reddish-gray some gravel			
	30					
	40					
	50					
4904.5			Top of bedrock			
	60		Bas.-gr.-bl., ves., h. frac., red cl. in ves. and on frac. sur.	100	1	Cemented hole
				100		
4894	70	-15-	--brec., ves.	55		
4885			--frac., no ves.			
4883		-17-	--Brec.			
		-17a-	--ves., reddish color, h. frac., cal. in ves.	84		
			--h. frac., gr.-bl.	100		
				100		
4870.5		-18-	--ves., h. frac., cal. in ves.	100		
			Clay, red, stiff, silty zones Basal sediments	0		Lost last 4.5 ft of core in hole
4864.8			Bottom of hole			

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Hole No. DH 252

DRILLING LOG	DIVISION	INSTALLATION	SHEET 1 OF 2 SHEETS

1. PROJECT: Earthquake Hazard Study
2. LOCATION (Coordinates or Station): Birie Dam   Birie, Idaho
3. DRILLING AGENCY: Corps of Engineers, Walla Walla District
4. HOLE NO. (As shown on drawing title and file number): DH 252
5. NAME OF DRILLER: Don Keys
6. DIRECTION OF HOLE: [x] VERTICAL [ ] INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN: 90.8 ft
8. DEPTH DRILLED INTO ROCK: 31.3 ft
9. TOTAL DEPTH OF HOLE: 122.1 ft
10. SIZE AND TYPE OF BIT: BX for coring
11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MSL
12. MANUFACTURER'S DESIGNATION OF DRILL:
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED | UNDISTURBED
14. TOTAL NUMBER CORE BOXES: 1
15. ELEVATION GROUND WATER:
16. DATE HOLE: STARTED 1 Aug 78 | COMPLETED 22 June 79
17. ELEVATION TOP OF HOLE: 4970
18. TOTAL CORE RECOVERY FOR BORING: 53 %
19. SIGNATURE OF INSPECTOR:

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
4970			Random fill-cl. to boulder size			4" casing in top 17 ft of hole
	10					
			Alluvium-sand gravel and boulders			NX casing
	20					
	30					
	40					
	50					
	60					
	70					
	80		Basalt boulder ~1' thick			Cemented hole
						Aug 1978 Stopped drilling at 90.8' pulled NX casing and left BX casing in hole
4879.2	90		Top Bedrock			
			Bas.-gr.-bl. --ves., h. frac.	0		Resumed drilling June 79
			--m. frac., some ves.	71	1	
	100					

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Hole No. DH 252

DRILLING LOG	DIVISION	INSTALLATION	SHEET 2 OF 2 SHEETS

1. PROJECT: Earthquake Hazard Study	10. SIZE AND TYPE OF BIT: BX for coring
2. LOCATION (Coordinates or Station): Ririe Dam Ririe, Idaho	11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MSL
3. DRILLING AGENCY: Corps of Engineers, Walla Walla District	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number): DH 252	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED / UNDISTURBED
5. NAME OF DRILLER: Don Keys	14. TOTAL NUMBER CORE BOXES: 1
6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
7. THICKNESS OF OVERBURDEN: 90.8 ft	16. DATE HOLE: STARTED 1 Aug 78; COMPLETED 28 June 79
8. DEPTH DRILLED INTO ROCK: 31.3 ft	17. ELEVATION TOP OF HOLE: 4970
9. TOTAL DEPTH OF HOLE: 122.1 ft	18. TOTAL CORE RECOVERY FOR BORING: 53 %
	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
4870	100		--h. frac., ves., cal. in ves., reddish zones --m. frac., some ves.	88	1	
	110			49		High clay content in return water
4857.9		-18-	Cl., red, stiff, silty zones Basal sediments			Red clay on end core
				0		Lost core, probably washed out, return water had high clay-silt content
	120			49		
4847.9			Bottom of hole			
	130					

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PROJECT | HOLE NO. DH 252

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Hole No. DH 253

DRILLING LOG	DIVISION	INSTALLATION	SHEET 1 OF 2 SHEETS

1. PROJECT: Earthquake Hazard Study	10. SIZE AND TYPE OF BIT: NX
2. LOCATION (Coordinates or Station): Ririe Dam, Ririe, Idaho	11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MSL
3. DRILLING AGENCY: Corps of Engineers, Walla Walla District	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number): DH 253	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED: — UNDISTURBED:
5. NAME OF DRILLER: Don Keys	14. TOTAL NUMBER CORE BOXES: 6
6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER: 20 ft
	16. DATE HOLE — STARTED: 29 June 1979 — COMPLETED: 18 July 1979
	17. ELEVATION TOP OF HOLE: 4970
7. THICKNESS OF OVERBURDEN: 90.0 ft	18. TOTAL CORE RECOVERY FOR BORING: 89 %
8. DEPTH DRILLED INTO ROCK: 89.7 ft	19. SIGNATURE OF INSPECTOR
9. TOTAL DEPTH OF HOLE: 179.7 ft	

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
4970			Random fill--cl. to boulder size			
	10		Silty sand and gravel			
	20					Water table at 20 ft
			Silty clay			
	30		Sand, gravel, and boulders			
	40					
	50					
	60					
	70					
	80					
4880	90		Top of bedrock			
			Bas., gr.-bl., h. frac., red clay in frac. surfaces	59		
4877		-15-	--Brec.	64	Box 1	
				53		
4873		-15a-	--sandy-silty, cl., red			
	100			44		

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Hole No. DH 253

DRILLING LOG

DIVISION

INSTALLATION

SHEET
OF 2 SHEETS

1. PROJECT: Earthquake Hazard Study
2. LOCATION (Coordinates or Station): Ririe Dam Ririe, Idaho
3. DRILLING AGENCY: Corps of Engineers, Walla Walla District
4. HOLE NO. (As shown on drawing title and file number): DH 253
5. NAME OF DRILLER: Don Keys
6. DIRECTION OF HOLE: ☒ VERTICAL ☐ INCLINED ______ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN: 90.0 ft
8. DEPTH DRILLED INTO ROCK: 89.7 ft
9. TOTAL DEPTH OF HOLE: 179.7 ft
10. SIZE AND TYPE OF BIT: NX
11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MSL
12. MANUFACTURER'S DESIGNATION OF DRILL
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED | UNDISTURBED
14. TOTAL NUMBER CORE BOXES: 6
15. ELEVATION GROUND WATER: 90 ft
16. DATE HOLE: STARTED 29 June 1979 | COMPLETED 16 July 1979
17. ELEVATION TOP OF HOLE: 4970
18. TOTAL CORE RECOVERY FOR BORING: 89 %
19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
4870						
4868.5			Clay, red, stiff, with bas. boulders			
4863		-16-	Bas., m. frac., ves., cl. in frac. and ves.	78	Box 1	
	110			79		
			--frac., ves.	83		
				100		
	120		--fra., few ves.		Box 2	
				100		
	130					
				100		
			--m. frac., ves. with cal. filling some ves.		Box 3	
				100		
4828	140	-17-	--brec.			
				79		
4819	150	-17a-	--fra., ves. with cal.		Box 4	
			--frac., no ves.			
				100		
	160		--frac., no ves., greenish cl. on frac. surfaces			
				100		
			--frac., no ves., green cl. in frac., cal. healed frac.	100		
	170				Box 5	
4797.4		-18-	Cl., red, stiff, silty-sandy zones Basal sediments	94		
				94		
4790.3	180		Bottom of hole	85	Box 6	

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PROJECT

HOLE NO. DH 253

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Hole No. DH 254

DRILLING LOG	DIVISION	INSTALLATION	SHEET 1 OF 2 SHEETS

1. PROJECT: Earthquake Hazard Study-Ririe Dam	10. SIZE AND TYPE OF BIT: NX
2. LOCATION (Coordinates or Station): Ririe Dam, Ririe Idaho	11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MSL
3. DRILLING AGENCY: Corps of Engineers, Walla Walla District	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number): DH 254	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED: None; UNDISTURBED:
5. NAME OF DRILLER: Don Keys	14. TOTAL NUMBER CORE BOXES: 2
6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER: 4948 ft
	16. DATE HOLE: STARTED 19 July 1979; COMPLETED 27 July 1979
	17. ELEVATION TOP OF HOLE: 4961.8
7. THICKNESS OF OVERBURDEN: 84.8 ft	18. TOTAL CORE RECOVERY FOR BORING: 65 %
8. DEPTH DRILLED INTO ROCK: 35.3 ft	19. SIGNATURE OF INSPECTOR
9. TOTAL DEPTH OF HOLE: 120.1 ft	

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
4961.8			Clayey silt with cobbles			
			Clayey silt, some gravel and sand			
	10					
4947.8			Water table			
	20					
			Sand and gravel			
	30					
	40					
	50					
	60					
	70					
	80					
			Top Bedrock			
4877.2			--Bas., gr.-bl., frac., red cl. on frac. surfaces	100	Box 1	Lot of cl. in return water from 88 ft to 98 ft
4872.8	90	-15-	--brec., ves.	61		
				26		
				100		
4863.8	100	-16-	--highly frac., red clay on frac. surfaces	94		

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PROJECT | HOLE NO. DH 254

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Hole No. DH 254

DRILLING LOG	DIVISION	INSTALLATION	SHEET 2 OF 2 SHEETS

1. PROJECT Earthquake Hazard Study - Ririe Dam	10. SIZE AND TYPE OF BIT NX
2. LOCATION (Coordinates or Station) Ririe Dam Ririe, Idaho	11. DATUM FOR ELEVATION SHOWN (TBM or MSL) MSL
3. DRILLING AGENCY Corps of Engineers, Walla Walla District	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number) DH 254	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN — DISTURBED: None; UNDISTURBED: None
5. NAME OF DRILLER Don Keys	14. TOTAL NUMBER CORE BOXES 2
6. DIRECTION OF HOLE [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER 4948 ft
	16. DATE HOLE — STARTED: 19 July 1979; COMPLETED: 27 July 1979
7. THICKNESS OF OVERBURDEN 84.8 ft	17. ELEVATION TOP OF HOLE 4961.8 ft
8. DEPTH DRILLED INTO ROCK 35.3 ft	18. TOTAL CORE RECOVERY FOR BORING 65 %
9. TOTAL DEPTH OF HOLE 120.1 ft	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
4861.8						
4859.8		17	--brec., ves., cal. filling some ves.	90	Box 2	Hole caving in
4855.3		17a		47 100		Lot of clay in return water from 102 to bottom of basalt
				95		
4850.6	110	18		69		Cemented hole
			Cl., red, stiff Basal sediments	0		Clay and silt washed away (no core from 112 ft to bottom of hole) High clay-silt content in return water, no basalt cuttings
4841.7	120		Bottom of hole	0		

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT) PROJECT HOLE NO. DH 254

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Hole No. DH 255

DRILLING LOG

DIVISION	INSTALLATION	SHEET 1 OF 2 SHEETS

1. PROJECT: Earthquake Hazard Study	10. SIZE AND TYPE OF BIT: NX
2. LOCATION (Coordinates or Station): Ririe Dam Ririe, Idaho	11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MSL
3. DRILLING AGENCY: Corps of Engineers, Walla Walla District	12. MANUFACTURER'S DESIGNATION OF DRILL:
4. HOLE NO. (As shown on drawing title and file number): DH 255	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED / UNDISTURBED
5. NAME OF DRILLER: Don Keys	14. TOTAL NUMBER CORE BOXES: 8
6. DIRECTION OF HOLE: [x] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER: 4948
	16. DATE HOLE: STARTED 28 July 1979; COMPLETED 7 Aug 1979
7. THICKNESS OF OVERBURDEN: 54.2 ft	17. ELEVATION TOP OF HOLE: 4962.5
8. DEPTH DRILLED INTO ROCK: 128.6 ft	18. TOTAL CORE RECOVERY FOR BORING: 83 %
9. TOTAL DEPTH OF HOLE: 182.8 ft	19. SIGNATURE OF INSPECTOR:

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
4962.5			Random fill			
			Silty cl., sand and gravel			
	10					Groundwater at 14 ft
4948.5						
	20					
	30					
	40					
	50		Clay, silty, tan			
4908.2			Top of bedrock			
			Bas., gr.-bl.			Probe cut8 ft into bed-rock
	60		--h. frac., ves., red cl. in frac.	0		
				100		
				90		
	70					Hole caving in
			--frac., no ves.	93	Box 1	
				96		
	80		--m. frac., no ves.	95		Cement hole
				100		
4878		-15-	--brec.	100		
			--m. frac., ves.	48		High clay content in return water from 85 to 92 ft.
			--brec.			
	90			81	Box 2	
4850		-15a-	Clay, sandy-silty, red, stiff			
4865		-16-	--Bas., gr.-bl., highly frac., ves., red cl. in frac. & ves.	86		Artesian beneath cl.
				56	Box 3	104.4 ft head Cemented hole

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PROJECT | HOLE NO. DH 255

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Hole No. DH 255

DRILLING LOG

DIVISION:

INSTALLATION:

SHEET 2 OF 2 SHEETS

1. PROJECT: Earthquake Hazard Study
2. LOCATION (Coordinates or Station): Ririe Dam   Ririe, Idaho
3. DRILLING AGENCY: Corps of Engineers, Walla Walla District
4. HOLE NO. (As shown on drawing title and file number): DH 255
5. NAME OF DRILLER: Don Keys
6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN: 54.2 ft
8. DEPTH DRILLED INTO ROCK: 128.6 ft
9. TOTAL DEPTH OF HOLE: 182.6 ft
10. SIZE AND TYPE OF BIT: NX
11. DATUM FOR ELEVATION SHOWN (TBM or MSL):
12. MANUFACTURER'S DESIGNATION OF DRILL:
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED: UNDISTURBED:
14. TOTAL NUMBER CORE BOXES:
15. ELEVATION GROUND WATER:
16. DATE HOLE: STARTED 28 July 1979; COMPLETED 7 August 1979
17. ELEVATION TOP OF HOLE: 4962.5
18. TOTAL CORE RECOVERY FOR BORING: 83 %
19. SIGNATURE OF INSPECTOR:

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
4862			--M. frac., ves., red cl. in frac. and ves.	100		
				100	Box 3	
	110		--Red, m. frac., red cl. in frac. and ves.			
			--Frac., ves., gr.-bl., red cl. in frac. and ves.	100+		
			--frac., few ves.			
	120			95	Box 4	
	130			100		
					Box 5	
			--H. frac., ves., cal. in ves.	100+		
	140		--Frac., few ves.	100		
4820		-17-	--Brec. and h. frac., red cl. and cal. in ves.	100		
4816.5		-17a-	--H. frac., red cl. and cal. in frac. and ves.		Box 6	
	150		--frac., cal.			
			--h. frac., ves., cal. and red cl. in frac. and ves.	95		
			--h. frac., ves. red, red cl. and cal. in frac. and ves.	100		
			--h. frac., ves., cal. and red cl. in ves. and frac.			
	160		--frac., few ves., cal. and red cl. in frac.	93		
			--h. frac., ves., cal. and red cl. in ves. and frac.	100+	Box 7	
4794.5	170	-18-	--frac., few ves., cl. in frac., cal.			
			Basal sediments--cl. red, sandy-silty zones	47		
	180					
4779.9			Bottom of hole	73	Box 8	

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PROJECT

HOLE NO. DH 255

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Hole No. DH 256

DRILLING LOG	DIVISION	INSTALLATION	SHEET 1 OF 2 SHEETS

1. PROJECT: Earthquake Hazard Study
2. LOCATION (Coordinates or Station): Ririe Dam Ririe, Idaho
3. DRILLING AGENCY: Corps of Engineers, Walla Walla District
4. HOLE NO. (As shown on drawing title and file number): DH 256
5. NAME OF DRILLER: Don Keys
6. DIRECTION OF HOLE: [x] VERTICAL [ ] INCLINED ________ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN: 32.1 ft
8. DEPTH DRILLED INTO ROCK: 148.7 ft
9. TOTAL DEPTH OF HOLE: 180.8 ft
10. SIZE AND TYPE OF BIT: NX
11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MSL
12. MANUFACTURER'S DESIGNATION OF DRILL:
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED | UNDISTURBED
14. TOTAL NUMBER CORE BOXES:
15. ELEVATION GROUND WATER:
16. DATE HOLE: STARTED 11 Aug 1979; COMPLETED 27 Aug 1979
17. ELEVATION TOP OF HOLE: 4967.3
18. TOTAL CORE RECOVERY FOR BORING: 90 %
19. SIGNATURE OF INSPECTOR:

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
4967.3			Random fill			
	10		Boulders, silt, gravel			
	20					Initial and final water-table 17 ft
			Silty gray clay			
	30		Talus			
4935.2			Bas., frac., gr.-bl., no ves., gray cl. & cal. in frac			No water return
			--Brec.	90		
			--frac., gray cl. and cal. in frac.	63		
	40		--h. frac., with gray cl. & cal. in frac.	[illegible]	Box 1	Cemented hole at 46 ft (1 1/2 sacks)
			--brec.	[illegible]8		
4915.6	50		NO CORE	18		No core, from 51.7 ft to 56.8 ft, no water return; high water pressure, cemented hole at 56.8 ft (1 1/4 sack)
4910.5			Gray clay with bas. frac., cl. reacts with HCL	0		
4909.1			Top of Bedrock			
	60		Bas. , m. frac., cal.	85		
4906.3		-13-	Red clay			
4905.3		-14-	Bas. , h. frac., ves., red cl, & cal.	100+		
				0		
			--frac. ves.	100+	Box 2	Watertable 11 ft
	70		--h. frac., ves., red cl. & cal.	91		Cemented hole (3 sacks cement)
			--frac., ves., cl. & cal.			Watertable 7.8 ft
			--m. frac., few ves.	100		
	80		--h. frac., few ves.	100		
				100	Box 3	
			--frac., few ves., cal. in ves.	100		
4879.3		-15-	--brec., ves., cal.			
	90		--h. frac., ves.	100		
			--brec., ves.		Box 4	
4871.3		-15a-	Clay, tan, silty, sandy, bas. frac.	100		
4969.3	100	-16-	--frac., ves.	100		Watertable 7.5 ft

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PROJECT | HOLE NO. DH 256

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Hole No. DH 256

DRILLING LOG

DRILLING LOG	DIVISION	INSTALLATION	SHEET 2 OF 2 SHEETS

1. PROJECT: Earthquake Hazard Study	10. SIZE AND TYPE OF BIT: NX
2. LOCATION (Coordinates or Station): Ririe Dam Ririe, Idaho	11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MSL
3. DRILLING AGENCY: Corps of Engineers, Walla Walla District	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number): DH 256	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED / UNDISTURBED
5. NAME OF DRILLER: Don Keys	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE: ☒ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
	16. DATE HOLE: STARTED 11 Aug 79; COMPLETED 27 Aug 79
7. THICKNESS OF OVERBURDEN: 32.1 ft	17. ELEVATION TOP OF HOLE: 4963.3
8. DEPTH DRILLED INTO ROCK: 148.7 ft	18. TOTAL CORE RECOVERY FOR BORING: 90 %
9. TOTAL DEPTH OF HOLE: 180.8 ft	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
4867.3			Bas., gr.-bl., frac. ves.			
			--frac., no ves.	98		
			--h. frac.			
			--brec.		Box 5	
			--m. frac., ves., red	95		
	110		--frac., large ves., gr.-bl.			
			--frac., few ves.			
			--h. frac. few ves.	98		
			--frac., few ves., cal., alternating section of red weathered and gray unweathered		Box 6	
	120			98		
			--h. frac.			
			--m. frac., few ves., weathered sections			
	130		--frac., few ves.	100+	Box 7	
			--frac., no ves., black			
			--frac., no ves., gr.-bl.	100		
4825.8	140	-17-	--brec., cal.			
			--h. frac., ves., cal.			
			--brec.	100	Box 8	Watertable 6.5 ft
			--h. frac., ves. clay			
			--brec. and h. frac.	100		
	150					
				90		
4811.8		-17a-	--fra., ves., red cl., reddish color			
			--frac., ves., gr.-bl.	100+		
	160		--frac., few ves.		Box 9	
			--m. frac., ves., cal., red cl. in frac.	100		
	170		--frac., few ves., cal.			
			--m. frac., ves., green cal. and cl. in ves. and frac.	86	Box 10	Watertable 5.7 ft
4791.8		-18-	Cl., red, sandy-silty zones. Basal sediments	97		
4786.5	180		--bottom of hole			

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Hole No. DH 257

DRILLING LOG	DIVISION	INSTALLATION	SHEET 1 OF 2 SHEETS

1. PROJECT: Earthquake Hazard Study
2. LOCATION (Coordinates or Station): Ririe Dam, Ririe, Idaho
3. DRILLING AGENCY: Corps of Engineers, Walla Walla District
4. HOLE NO. (As shown on drawing title and file number): DH 257
5. NAME OF DRILLER: Don Keys
6. DIRECTION OF HOLE: [x] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN: 57.9 ft
8. DEPTH DRILLED INTO ROCK: 124.3 ft
9. TOTAL DEPTH OF HOLE: 182.2 ft
10. SIZE AND TYPE OF BIT: NX
11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MSL
12. MANUFACTURER'S DESIGNATION OF DRILL:
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED | UNDISTURBED
14. TOTAL NUMBER CORE BOXES:
15. ELEVATION GROUND WATER:
16. DATE HOLE: STARTED 27 Aug 79 | COMPLETED 4 Sep 79
17. ELEVATION TOP OF HOLE: 4967.3
18. TOTAL CORE RECOVERY FOR BORING: 83 %
19. SIGNATURE OF INSPECTOR:

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
4967.3			Random fill			
	10		Silty clay			
	20		Gravel and silty grayish clay			
	30					
	40					
	50		Silty gray clay			
4909.4						
4907.3			Top of bedrock Bas., brec., gr.-bl.	60		
	60	-14-	--Bas., m. frac., few ves., small crystal laths of feldspar, red clay in frac.	100	Box 1	
			--mod. to h. frac., ves., cl. in frac. and ves.	100		
	70		--frac., ves., red cl. in frac. cal. --frac., few large ves. with cal. crystals	99		Watertable 5.6 ft at 74.0 ft; cal. crystals in ves.
			--mod. to h. frac., ves., cal & red clay in frac. and ves.	100+		
	80		--frac., few ves. cal.	98	Box 2	
			--h. frac., ves., cal and red clay in frac. and ves.	92		
4978.3	90	-15-	--brec., ves.	19	Box 3	high clay content in return water
4869.3	100	-16-	--ves., no frac., red cl. and cal. in ves.			

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Hole No. DH 257

DRILLING LOG

DIVISION	
INSTALLATION	
SHEET	OF 2 SHEETS
1. PROJECT	Earthquake Hazard Study
2. LOCATION (Coordinates or Station)	Ririe Dam, Ririe, Idaho
3. DRILLING AGENCY	Corps of Engineers, Walla Walla District
4. HOLE NO. (As shown on drawing title and file number)	DH 257
5. NAME OF DRILLER	Don Keys
6. DIRECTION OF HOLE	☒ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN	57.9 ft
8. DEPTH DRILLED INTO ROCK	124.3 ft
9. TOTAL DEPTH OF HOLE	182.2 ft
10. SIZE AND TYPE OF BIT	NX
11. DATUM FOR ELEVATION SHOWN (TBM or MSL)	MSL
12. MANUFACTURER'S DESIGNATION OF DRILL	
13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN	DISTURBED: / UNDISTURBED:
14. TOTAL NUMBER CORE BOXES	
15. ELEVATION GROUND WATER	
16. DATE HOLE	STARTED: 27 Aug 79 / COMPLETED: 4 Sep 79
17. ELEVATION TOP OF HOLE	4967.3
18. TOTAL CORE RECOVERY FOR BORING	83 %
19. SIGNATURE OF INSPECTOR	

ELEVATION (a)	DEPTH (b)	LEGEND (c)	CLASSIFICATION OF MATERIALS (Description) (d)	% CORE RECOVERY (e)	BOX OR SAMPLE NO. (f)	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) (g)
4867.3			Bas., m. frac., few ves., red cl. & cal. in ves.			
			--frac., ves., red, cal. & red cl. in ves.	80	Box 3	
			--frac., ves., red cl. & cal. in ves., large ves.			
	110		--frac. to m. frac., few ves. red clay in frac.	100+	Box 4	
				100		
	120		--h. frac., weathered brown	100		
			--m. frac., weathered brown zones			
			--h. frac., weathered	100	Box 5	
			--m. frac., no ves.			
	130		--m. frac., highly weathered brown, cal. healed frac.			
			--frac., few ves., weathered zone	100		
			--mod. to highly frac., ves., red cl. in ves.	95		
	140			100	Box 6	
4822.3		-17-	--h. frac. to brec., ves., cal. and red cl. in frac. & ves.	60		
4814.3	150	-17a-	--m. frac., few ves., cal., red clay in ves. & frac.	94		
			--h. frac., ves., cal. in ves. cl. in ves. and frac.		Box 7	
	160		--frac., few ves., red cal. in ves. and frac.	54		
			--frac., ves., cal.	100+		
			--h. frac., ves.			
			--m. frac., few ves., cal.			
	170		--frac., few ves., weathered brownish-red, cal, & red cl. in frac. and ves.	80	Box 8	
4792.3		-18-	Clay, red, stiff, sandy-silty zones			
			Basal sediments			
4785.1	180			60		
			Bottom hole			
	190					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT)

PROJECT | HOLE NO. DH 257

Reproduced From Best Available Copy

Hole No. [illegible]

DRILLING LOG	DIVISION	INSTALLATION	SHEET 1 OF 2 SHEETS

1. PROJECT: Earthquake Hazard Study	10. SIZE AND TYPE OF BIT: [illegible] 1/4 inch rock bit
2. LOCATION (Coordinates or Station): Ririe Dam, Ririe, Idaho	11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MSL
3. DRILLING AGENCY: Corps of Engineers, Walla Walla District	12. MANUFACTURER'S DESIGNATION OF DRILL: Pneumatic
4. HOLE NO. (As shown on drawing title and file number): PN 123	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED / UNDISTURBED
5. NAME OF DRILLER: Jim Knick	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
7. THICKNESS OF OVERBURDEN: 77.4 ft	16. DATE HOLE: STARTED 11 Sept 79; COMPLETED 4 Sept 79
8. DEPTH DRILLED INTO ROCK: 66.6 ft	17. ELEVATION TOP OF HOLE: 4961.4
9. TOTAL DEPTH OF HOLE: 144.0 ft	18. TOTAL CORE RECOVERY FOR BORING: 0 %
	19. SIGNATURE OF INSPECTOR

ELEVATION (a)	DEPTH (b)	LEGEND (c)	CLASSIFICATION OF MATERIALS (Description) (d)	% CORE RECOVERY (e)	BOX OR SAMPLE NO. (f)	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) (g)
4961.4			Random fill			
			Alluvium Gravel, sand, silt			
	10					
4947.3						Watertable at 14.1 ft after hole plugged
	20					
	30					
	40					
	50					
	60					
	70		Silty gray clay, Gravel			
4884			Top bedrock Bas. with reddish colored clay frag. ranging up to coarse sand size			Hole plugged to stop artesian flow
	80					
	90					
	100					Artesian between 96.3 ft and 101.0 ft. Head 1.6 ft above ground surface

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT) | PROJECT | HOLE NO. PN 123

Reproduced From Best Available Copy

Hole No. PN 123

DRILLING LOG	DIVISION	INSTALLATION	SHEET OF SHEETS

1. PROJECT: Earthquake Hazard Study	10. SIZE AND TYPE OF BIT: [illegible] inch rock bit
2. LOCATION (Coordinates or Station): Ririe Dam, Ririe, Idaho	11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MSL
3. DRILLING AGENCY: Corps of Engineers, Walla Walla District	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number): PN 123	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED / UNDISTURBED
5. NAME OF DRILLER: Jim Knick	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE: [X] VERTICAL [ ] INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER
	16. DATE HOLE: STARTED 1 Sept 79; COMPLETED 4 Sept 79
7. THICKNESS OF OVERBURDEN: 77.4 ft	17. ELEVATION TOP OF HOLE: 4972
8. DEPTH DRILLED INTO ROCK: 66.6 ft	18. TOTAL CORE RECOVERY FOR BORING: 0 %
9. TOTAL DEPTH OF HOLE: 144.0 ft	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
4861.4			Basalt with reddish colored clay fragments ranging up to coarse sand size			
	110					
	120					
	130					
	140					
4828.0			Bottom of hole			
4817.4						
	150					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT) PROJECT HOLE NO. PN 123

Reproduced From Best Available Copy

Hole No. PN 124

DRILLING LOG	DIVISION	INSTALLATION WES	SHEET 1 OF 2 SHEETS

1. PROJECT Earthquake Hazard Study	10. SIZE AND TYPE OF BIT 2 1/4 inch rock bit
2. LOCATION (Coordinates or Station) Ririe Dam Ririe, Idaho	11. DATUM FOR ELEVATION SHOWN (TBM or MSL) MSL
3. DRILLING AGENCY Corps of Engineers, Walla Walla District	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number) PN 124	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED / UNDISTURBED
5. NAME OF DRILLER Don Keys	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE [X] VERTICAL [ ] INCLINED ______ DEG. FROM VERT.	15. ELEVATION GROUND WATER 4947.9 ft
	16. DATE HOLE: STARTED 6 Sept 79; COMPLETED 7 Sept 79
7. THICKNESS OF OVERBURDEN 74 ft	17. ELEVATION TOP OF HOLE 4962 ft
8. DEPTH DRILLED INTO ROCK 52 ft	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE 126 ft	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
4962			Fill-gravel and random fill			
	10					
			alluvium-sand, gravel and boulders			
	20					
	30					
	40					
	50					
	60					
	70		Clay, gray, silty			
4888			Top bedrock Bas., gr.-bl., with reddish colored clay fragments ranging up to coarse sand size			No water return until reached depth of 100 ft
	80					
	90					
	100					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE (TRANSLUCENT) | PROJECT | HOLE NO. PN 124

Reproduced From Best Available Copy

Hole No. PN 124

DRILLING LOG	DIVISION	INSTALLATION	SHEET 2 OF 2 SHEETS

1. PROJECT: Earthquake Hazard Stud.	10. SIZE AND TYPE OF BIT
2. LOCATION (Coordinates or Station): Ririe Dam, Ririe, Idaho	11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MSL
3. DRILLING AGENCY: Corps of Engineers, Walla Walla District	12. MANUFACTURER'S DESIGNATION OF DRILL
4. HOLE NO. (As shown on drawing title and file number): PN 124	13. TOTAL NO. OF OVER-BURDEN SAMPLES TAKEN: DISTURBED / UNDISTURBED
5. NAME OF DRILLER: Don Keys	14. TOTAL NUMBER CORE BOXES
6. DIRECTION OF HOLE: ☒ VERTICAL ☐ INCLINED ____ DEG. FROM VERT.	15. ELEVATION GROUND WATER: 4947.9
	16. DATE HOLE: STARTED 6 Sept 79; COMPLETED 7 Sept 79
7. THICKNESS OF OVERBURDEN: 74 ft	17. ELEVATION TOP OF HOLE: 4962 ft
8. DEPTH DRILLED INTO ROCK: 52 ft	18. TOTAL CORE RECOVERY FOR BORING %
9. TOTAL DEPTH OF HOLE: 126 ft	19. SIGNATURE OF INSPECTOR

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	100		Bas., with reddish colored clay fragments ranging up to coarse sand size			water return
	110					return water red from high clay content
	120					
4836			Bottom of hole			
	130					

ENG FORM 1836 MAR 71 PREVIOUS EDITIONS ARE OBSOLETE. (TRANSLUCENT) PROJECT HOLE NO. PN 124

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APPENDIX B

LIST OF HISTORIC EARTHQUAKES WITHIN A RADIUS OF 200 KM OF RIRIE DAM

Table B1

Historic Earthquakes Within a Radius of 200 km of Ririe Dam, Idaho
(Intensity MM IV or Greater or Instrumentally Located)

Year	Date	Time MST	Locality	Coordinates Deg. N. Lat.	Coordinates Deg. W. Long.	Intensity MM	Magnitude	Felt Area (sq mi)	Source	Zone
1880	11 Jul	2200	Portage, Utah	42.0	112.3	VI	(5.0)		EHUS	C
1897	4 Nov	0229	Montana	45	113	VI	(5.0)		EHUS	—
1906	18 Oct	1906	Idaho	42.5	111.4	V		3,000	EHUS	B
1913	12 Apr	0125	SE Idaho	42	112	V		8,000	EHUS	—
1914	13 May	1015	SE Idaho	42	112	VII	(5.5)	8,000	EHUS	—
1915	8 May	0910	Wyoming	44.9	110.7	V		10,000	EHUS	A
1915	30 Jul	1150	N. Utah	41.8	112.2	V	(4.0)		EHUS	C
1917	12 Dec	0500	S. Idaho	43.0	111.3	V		8,000	EHUS	B
1923	23 Mar – 12 Apr	2100	Kelly, Wyoming	43.6	110.6	V		1,500	EHUS	—
1924	25 Nov	0710	SE Idaho	42.5	111.5	V		20,000	EHUS	B
1930	12 Jun	0215	Grover, Wyoming	42.6	111.0	VI	(5.0)		EHUS	B
1930	24 Aug – 22 Dec	various	Yellowstone N. P., Wyoming	44	111	IV-V			EHUS	A
1932	26 Jan	0313	W. Wyoming	43.6	110.8	V-VI	(5.0)	1,000	EHUS	—
1933	2 Nov	0926	Gray, Idaho	43.0	111.3	V			EHUS	B
1933	29 Nov	1000	Virginia City, Mont.	45.3	111.9	IV-V		200	EHUS	A
1936	14 Jan	2140	Yellowstone N. P., Wyoming	44	111	VI	(5.0)	1,200	EHUS	A
1942	5 Aug	1434	Yellowstone N. P., Wyoming	44	111	V			EHUS	A
1946	5 May	2130	N. Utah	41.8	112.0	V			EHUS	—
1947	23 Nov	0246	SW Montana	44.8	112.0	VIII	M = 6.2	150,000	EHUS	A
1948	23 Feb	1939	NW Wyoming	43.5	111.0	VI	(5.0)	1,500	EHUS	—
1950	27 Jun	2131	W. Yellowstone, Montana	44 3/4	110 1/2	VI	5.0		EHUS	A
1954	4 Jul	0933	Yellowstone N. P., Wyoming	44.9	110.8	V			EHUS	A
1958	28 Apr	1359	Yellowstone N. P., Wyoming	44	111	V			EHUS	A
1959	17 Aug	2337	Hebgen Lake, Mont.	44.8	111.1	X	M = 7.1	600,000	EHUS	A
1959	18 Aug	0142	Yellowstone N. P., Wyoming	44.8	110.7	VI	M = 6.0		EHUS	A

(Continued)

Table B1 (Continued)

Year	Date	Time MST	Locality	Coordinates Deg. N. Lat.	Coordinates Deg. W. Long.	Intensity MM	Magnitude	Felt Area (sq mi)	Source	Zone
1959	18 Aug	0826	Yellowstone N. P., Wyoming	44.9	110.7		M = 6.5 (1)			A
1959	18 Aug	1243	Yellowstone N. P., Wyoming	45.0	110.5		M = 6.5 (1)			A
1959	18 Aug	2104	SW Montana	44.9	111.6	V	M = 6.0		EHUS	A
1959	20 Aug	1211	Hebgen Lake, Mont.	45	111	V			EHUS	A
1959	23 Aug	0140	Hebgen Lake, Mont.	45	111	VI	(5.0)		EHUS	A
1959	30 Aug	0050	W. Yellowstone, Mont.	44.7	111.1	V			EHUS	A
1959	5 Sep	0510	Yellowstone N. P., Wyoming	44 3/4	111	VI	(5.0)		EHUS	A
1959	25 Sep	0540	Yellowstone N. P., Wyoming	44 3/4	111	V			EHUS	A
1959	26 Sep	0204	Yellowstone N. P., Wyoming	44 3/4	111	V			EHUS	A
1959	28 Sep	0106	Gallatin Gateway, Mont.	45	111	V			EHUS	A
1959	29 Sep	1836	Yellowstone N. P., Wyoming	45	111	VI	(5.0)		EHUS	A
1959	18 Oct	0509	West Yellowstone, Mont.	44.7	111.1	V			EHUS	A
1959	19 Oct	0200 - 0650	West Yellowstone, Mont.	44.7	111.1	V			EHUS	A
1959	1 Nov	1603	Yellowstone N. P., Wyoming	45	111	V			EHUS	A
1959	4 Nov	2142	Yellowstone N. P., Wyoming	44 3/4	111	V			EHUS	A
1959	8 Dec	0014	Ennis, Mont.	45.4	111.7	V			EHUS	A
1959	11 Dec	2323	W. Yellowstone, Mont.	44.7	111.1	V			EHUS	A
1959	12 Dec	1047	W. Yellowstone, Mont.	44.7	111.1	V			EHUS	A
1959	13 Dec	0050	W. Yellowstone, Mont.	45	110 1/2	V			EHUS	A
1959	13 Dec	0057	Yellowstone N. P., Wyoming	44 3/4	111	V			EHUS	A
1960	4 Jan	2104	Hebgen Lake, Mont.	44 1/2	111 1/2	V			EHUS	A

(Continued)

Table B1 (Continued)

Year	Date	Time MST	Locality	Coordinates Deg. N. Lat.	Coordinates Deg. W. Long.	Intensity MM	Magnitude	Felt Area (sq mi)	Source	Zone
1960	3 Feb	1130	Ennis, Montana	45.4	111.7	V			EHUS	A
1960	22 Mar	2015	Hebgen Lake, Mont.	44 1/2	111	V			EHUS	A
1960	21 Apr	1049	Hebgen Lake, Mont.	45	111	V			EHUS	A
1960	26 Apr	2132	Hebgen Lake, Mont.	44 1/2	111	V			EHUS	A
1960	7 Aug	0927	SE Idaho	42.4	111.5	VI	(5.0)	900	EHUS	B
1960	10 Aug	0042	SE Idaho	42.5	111.5	V			EHUS	B
1960	20 Aug	0102	SE Idaho	42.3	111.3	V			EHUS	B
1961	13 Mar	1228	Hebgen Dam, Mont.	44.9	111.4	V			EHUS	A
1961	6 Apr	2251	S. Madison Co., Mont.	44.8	112.0	V		2,500	EHUS	A
1961	29 Jun	0445	Yellowstone N. P., Wyoming	44 3/4	111	V			EHUS	A
1961	3 Dec	1841 - 2025	Virginia City, Mont.	45.3	111.9	V			EHUS	A
1962	26 Aug	0515 - 0622	Yellowstone N. P., Wyoming			V			EHUS	A
1962	30 Aug	0635	N. Utah	41.8	111.8	VII	(5.5)	65,000	EHUS	--
1962	4 Sep	~2000	Logan, Utah	41.7	111.8	V			EHUS	--
1962	7 Sep	AM	Lewiston, Utah	42	111.8	V			EHUS	--
1963	29 Jan	2251	Yellowstone N. P., Wyoming	45.0	110.8	V			EHUS	A
1963	8 Mar	0136	Yellowstone N. P., Wyoming	44.8	110.2	VI	M = 3.8		EHUS	A
1963	21 Mar	2135	Yellowstone N. P., Wyoming	44.8	110.5	V	M = 4.3		EHUS	A
1963	18 Apr	0343	Yellowstone N. P., Wyoming	44.8	110.3	V			EHUS	A
1963	23 Sep	2336	Yellowstone N. P., Wyoming	44.9	111.0	V	M = 3.1 M = 4.7		EHUS	A
1963	17 Dec	0230	Yellowstone N. P., Wyoming	44.9	111.0	V			EHUS	A
1963	20 Dec	0601	Hebgen Lake, Mont.	44.9	111.7	V	M = 4.3	3,000	EHUS	A
1964	27 Mar	1936	Near Ennis, Mont.	45.4	111.7	V			EHUS	A
1964	21 Oct	0039	Hebgen Lake, Mont.	44.8	111.6	V	M = 5.8	25,000	EHUS	A
1965	5 Jan	1901	SW Montana	44.9	112.7	VI	M = 5.1	12,000	EHUS	--

(Continued)

Table B1 (Continued)

Year	Date	Time MST	Locality	Coordinates Deg. N. Lat.	Coordinates Deg. W. Long.	Intensity MM	Magnitude	Felt Area (sq mi)	Source	Zone
1965	12 Jan	2044	E. Idaho	44.9	112.7	V			EHUS	—
1965	8 Oct	1235	Hebgen Lake, Mont.	44.8	111.1	V	M = 4.9		EHUS	A
1966	11 Oct	0030	Hebgen Lake, Mont.	44.9	111.1	V	M = 4.0		EHUS	A
1966	11 Oct	0448	W. Yellowstone, Mont.	44.7	111.1	V			EHUS	A
1966	11 Oct	1053	Hebgen Lake, Mont.	44.8	111.2	V	M = 4.3		EHUS	A
1967	10 Jan	0453	Hebgen Lake, Mont.	45.0	111.5	V	M = 3.8		EHUS	A
1971	4 Jan	1908	W. Montana	45.2	112.0	V	M_b = 3.6	2,500	EHUS	A
1971	3 Feb	0316*	Hebgen Lake, Mont.	44.9	111.0	—	—	—	EHUS	A
1971	3 Feb	1125*	Hebgen Lake, Mont.	44.9	111.0	—	—	—	—	A
1971	3 Feb	1952*	W. Montana	45.1	110.9	—	M_b=4.9	—	—	A
1971	21 Apr	0852*	Hebgen Lake, Mont.	44.8	111.3	—	M_b = 3.9	—	—	A
1971	23 Jun	0501*	Yellowstone N. P., Wyoming	44.0	110.4	—	—	—	—	A
1971	16 Jul	0354	E. Idaho	42.2	111.4	V	M_b = 3.6	—	—	B
1971	3 Dec	0535	Wyoming	42.3	110.4	—	M_b = 4.1	—	—	—
1972	13 Jan	2134	Virginia City, Mont.	45.0	111.6	IV	—	—	—	A
1972	6 Mar	0633	Utah-Idaho Border	41.9	111.6	V	—	—	—	—
1972	22 Jun	0439*	Yellowstone N. P., Wyoming	44.6	110.1	—	M_b = 3.9	—	—	A
1972	29 Aug	2141	Ennis, Mont.	—	—	IV	—	—	—	A
1972	23 Nov	2236	E. Idaho	42.5	111.2	IV	—	—	—	B
1973	15 Jan	0441*	Hebgen Lake, Mont.	44.6	111.3	—	—	—	—	A
1973	14 Feb	0611*	Hebgen Lake, Mont.	44.6	111.6	—	—			
1973	14 Feb	1357*	E. Idaho	43.9	111.2	—	—			
1973	1 Mar	0600*	Hebgen Lake, Mont.	44.8	111.1	—	M_b = 4.3			A
1973	24 Mar	2320*	Yellowstone N. P., Wyoming	44.0	110.2	—	—			A
1973	25 Mar	0956*	Yellowstone N. P., Wyoming	44.1	110.2	—	—			A

(Continued)

(Sheet 4 of 13)

Table B1 (Continued)

Year	Date	Time MST	Locality	Coordinates Deg. N. Lat.	Coordinates Deg. W. Long.	Intensity MM	Magnitude	Felt Area (sq mi)	Source	Zone
1973	25 Mar	1633*	Yellowstone N. P., Wyoming	44.5	110.5	—	$M_b = 3.4$			A
1973	26 Mar	0409*	Yellowstone N. P., Wyoming	44.4	110.4	—	—			A
1973	27 Mar	1003*	Yellowstone N. P., Wyoming	44.4	110.4	—	—			A
1973	27 Mar	1231*	Yellowstone N. P., Wyoming	44.4	110.4	—	—			A
1973	27 Mar	1243*	Yellowstone N. P., Wyoming	44.4	110.5	—	—			A
1973	27 Mar	1902*	Yellowstone N. P., Wyoming	44.4	110.5	—	—			A
1973	28 Mar	0239*	Yellowstone N. P., Wyoming	44.4	110.4	—	$M_b = 5.0$			A
1973	28 Mar	0302*	Yellowstone N. P., Wyoming	44.4	110.4	—	$M_b = 4.5$			A
1973	28 Mar	1007*	Yellowstone N. P., Wyoming	44.4	110.5	—	$M_b = 4.0$			A
1973	28 Mar	1538*	Yellowstone N. P., Wyoming	44.2	110.4	—	—			A
1973	29 Mar	1040*	Yellowstone N. P., Wyoming	44.1	110.2	—	—			A
1973	30 Mar	0010*	Yellowstone N. P., Wyoming	44.3	110.4	—	—			A
1973	30 Mar	0032*	Yellowstone N. P., Wyoming	44.4	110.4	—	$M_b = 4.6$			A
1973	30 Mar	0132*	Yellowstone N. P., Wyoming	44.4	110.4	—	$M_b = 3.7$			A
1973	30 Mar	0155*	Yellowstone N. P., Wyoming	44.6	110.6	—	—			A
1973	30 Mar	0213*	Yellowstone N. P., Wyoming	44.6	110.6	—	—			A

(Continued)

* Greenwich Mean Time.

Table B1 (Continued)

Year	Date	Time MST	Locality	Coordinates Deg. N. Lat.	Coordinates Deg. W. Long.	Intensity MM	Magnitude	Felt Area (sq mi)	Source	Zone
1973	30 Mar	0659*	Yellowstone N. P., Wyoming	44.4	110.4	--	--			A
1973	30 Mar	1436*	Yellowstone N. P., Wyoming	44.1	110.3	--	--			A
1973	31 Mar	1613*	Yellowstone N. P., Wyoming	44.4	110.6	--	--			A
1973	31 Mar	2033*	Yellowstone N. P., Wyoming	44.5	110.5	--	$M_b = 5.1$			A
1973	1 Apr	0944*	Yellowstone N. P., Wyoming	44.4	110.4	--	--			A
1973	2 Apr	1857*	Yellowstone N. P., Wyoming	44.4	110.4	--	--			A
1973	2 Apr	1948*	Yellowstone N. P., Wyoming	44.4	110.4	--	--			A
1973	4 Apr	1514*	Yellowstone N. P., Wyoming	44.6	110.6	--	--			A
1973	5 Apr	1630*	Yellowstone N. P., Wyoming	44.4	110.5	--	--			A
1973	6 Apr	2346*	Yellowstone N. P., Wyoming	44.7	110.6	--	--			A
1973	7 Apr	1919*	Yellowstone N. P., Wyoming	44.1	110.2	--	--			A
1973	9 Apr	1030	Yellowstone N. P., Wyoming	44.1	110.5	--	$M_b = 3.6$			A
1973	12 Apr	0315*	Yellowstone N. P., Wyoming	44.4	110.5	--	--			A
1973	12 Apr	0319*	Yellowstone N. P., Wyoming	44.4	110.5	--	--			A
1973	12 Apr	0324*	Yellowstone N. P., Wyoming	44.4	110.5	--	$M_b = 4.2$			A
1973	13 Apr	0650*	E. Idaho	42.1	112.6	--	--			C

(Continued)

* Greenwich Mean Time.

Table B1 (Continued)

Year	Date	Time MST	Locality	Coordinates Deg. N. Lat.	Coordinates Deg. W. Long.	Intensity MM	Magnitude	Felt Area (sq mi)	Source	Zone
1973	13 Apr	2345	E. Idaho	42.1	112.5	--	M_b = 4.7			C
1973	20 Apr	1906*	E. Idaho	43.9	111.1	--	--			--
1973	21 Apr	0800*	Yellowstone N. P., Wyoming	44.4	110.4	--	M_b = 3.6			A
1973	21 Apr	0026	Yellowstone N. P., Wyoming	44.4	110.4	--	M_b = 4.4			A
1973	9 Jun	1237*	Montana	45.0	111.1	--	--			A
1973	17 Jun	0917*	Hebgen Lake, Mont.	44.7	111.0	--	--			A
1973	27 Jun	0322*	Hebgen Lake, Mont.	44.6	111.2	--	--			A
1973	6 Aug	0626*	Yellowstone N. P., Wyoming	44.7	110.6	--	--			A
1973	27 Oct	0044*	E. Idaho	42.8	111.1	--	--			B
1973	20 Nov	2336*	E. Idaho	42.0	112.7	--	--			C
1974	6 Feb	0726*	Montana	45.1	111.01	--	--			A
1974	24 Mar	1504*	Yellowstone N. P., Wyoming	44.63	110.79	--	M_b = 3.8			A
1974	24 Mar	1507*	Yellowstone N. P., Wyoming	44.64	110.80	--	--			A
1974	24 Mar	2257*	Hebgen Lake, Mont.	44.50	111.08	--	--			A
1974	14 Apr	1332*	Hebgen Lake, Mont.	44.85	111.00	--	--			A
1974	9 Jun	0050*	Hebgen Lake, Mont.	44.80	111.05	II	M_L = 4.9			A
1974	9 Jun	0144*	Hebgen Lake, Mont.	44.93	111.34	-	--			A
1974	1 Jul	1823*	Hebgen Lake, Mont.	44.56	111.09		M_b = 4.8 M_L = 5.1			A
1974	3 Jul	0313*	Hebgen Lake, Mont.	44.64	111.23	--	--			A
1974	4 Jul	0310*	Hebgen Lake, Mont.	44.41	111.11	--	--			A
1974	30 Aug	1324*	Hebgen Lake, Mont.	44.49	111.10	--	--			A
1974	30 Aug	1335*	Hebgen Lake, Mont.	44.47	111.11	--	--			A
1974	30 Aug	1641*	Yellowstone N. P., Wyoming	44.70	110.8	V	M_b = 4.5 M_L = 4.5			A

(Continued)

* Greenwich Mean Time.

Table B1 (Continued)

Year	Date	Time MST	Locality	Coordinates Deg. N. Lat.	Coordinates Deg. W. Long.	Intensity MM	Magnitude	Felt Area (sq mi)	Source	Zone
1974	30 Aug	1655*	Hebgen Lake, Mont.	44.53	111.02	--	--			A
1974	30 Aug	1701*	Hebgen Lake, Mont.	44.70	111.23	--	--			A
1974	30 Aug	1704*	Hebgen Lake, Mont.	44.65	111.09	II	--			A
1974	30 Aug	1741*	Hebgen Lake, Mont.	44.58	111.12	II	--			A
1974	30 Aug	1933*	Hebgen Lake, Mont.	44.36	111.05	II	--			A
1974	30 Aug	1946*	Yellowstone N. P., Wyoming	44.64	110.77	II	$M_b = 4.5$			A
1974	18 Oct	0625*	Yellowstone N. P., Wyoming	44.73	110.74	II	$M_b = 4.4$			A
1974	18 Oct	0659*	Yellowstone N. P., Wyoming	44.74	110.74	II	$M_b = 3.5$			A
1974	20 Oct	0214*	Hebgen Lake, Mont.	44.47	110.01	II	--			A
1974	20 Oct	0219*	Hebgen Lake, Mont.	44.24	111.14	--	--			A
1974	20 Oct	0645*	Yellowstone N. P., Wyoming	44.94	110.86	--	--			A
1974	20 Oct	2249*	Yellowstone N. P., Wyoming	44.73	110.64	--	--			A
1974	20 Oct	2257*	Yellowstone N. P., Wyoming	44.78	110.89	--	--			A
1974	22 Oct	0843*	Yellowstone N. P., Wyoming	44.74	110.81	IV	$M_b = 4.6$			A
1974	29 Oct	0148*	Hebgen Lake, Mont.	44.63	111.31	--	$M_b = 4.0$			A
1974	30 Oct	0914*	Yellowstone N. P., Wyoming	44.82	110.79	--	$M_b = 3.9$			A
1974	28 Dec	1357*	Idaho-Utah Border	42.00	111.97	IV	$M = 2.8$			--
1975	25 Jan	2008*	Montana	45.07	111.47	V	$M_b = 4.2$	--		A
1975	31 Jan	0010	West Yellowstone	--	--	IV	--	--		A
1975	22 Feb	2115*	Yellowstone N. P., Wyoming	44.94	110.68	--	--	--		A

(Continued)

(Sheet 8 of 13)

* Greenwich Mean Time.

Table P1 (Continued)

Year	Date	Time MST	Locality	Coordinates Deg. N. Lat.	Deg. W. Long.	Intensity MM	Magnitude	Felt Area (sq mi)	Source	Zone
1975	11 Mar	1330*	Hebgen Lake, Mont.	44.94	111.45	--	--			A
1975	27 Mar	0448*	E. Idaho	42.07	112.55	V	M_b = 4.4			C
1975	28 Mar	0231*	E. Idaho	42.06	112.55	VIII	M_b = 6.1	160,000		C
1975	28 Mar	1311*	E. Idaho	42.05	112.48	IV	M_b = 4.3			C
1975	28 Mar	1615*	E. Idaho	42.03	112.53	III	M_b = 4.1			C
1975	29 Mar	0544*	E. Idaho	42.08	112.45	IV	M_b = 4.3			C
1975	29 Mar	1301*	E. Idaho	42.02	112.52	V	M_b = 4.7			C
1975	30 Mar	0656*	E. Idaho	42.02	112.58	--	M_b = 4.3			C
1975	30 Mar	0722*	E. Idaho	42.03	112.62	--	M_b = 4.0			C
1975	30 Mar	0732*	E. Idaho	42.02	112.61	--	M_b = 4.3			C
1975	30 Mar	1006*	E. Idaho	42.10	112.64	--	M_b = 3.9			C
1975	30 Mar	1217*	E. Idaho	42.04	112.54	--	M_b = 4.0			C
1975	30 Mar	1256*	E. Idaho	42.01	112.59	--	M_b = 4.0			C
1975	2 Apr	2106*	E. Idaho	42.09	112.44	--	M_b = 4.7			C
1975	4 Apr	0450*	E. Idaho	44.81	112.99	--	M_b = 3.8			C
1975	4 Apr	1346*	E. Idaho	42.01	112.48	--	M = 2.8			C
1975	6 Apr	2105*	E. Idaho	42.02	112.49	--	M = 3.2			C
1975	7 Apr	1342*	E. Idaho	42.04	112.49	--	M_b = 4.6			C
1975	7 Apr	1401*	E. Idaho	42.15	112.59	--	M = 3.1			C
1975	7 Apr	1443*	E. Idaho	42.04	112.50	--	M_b = 4.4			C
1975	8 Apr	0348*	N. Utah	41.88	112.37	--	M_b = 4.0			C
1975	10 Apr	1021*	E. Idaho	42.01	112.55	--	M = 3.2			C
1975	18 Jun	0542*	E. Idaho	43.37	110.96	--	M_b = 3.3			B
1975	20 Jun	1054*	Montana	45.00	111.22	IV	--			A
1975	23 Jun	1923*	Hebgen Lake, Mont.	44.93	111.08	--	--			A
1975	27 Jun	1340*	Hebgen Lake, Mont.	44.92	111.46	--	--			A
1975	30 Jun	0326*	E. Idaho	42.11	112.47	II	--			C

(Continued)

* Greenwich Mean Time.

Table B1 (Continued)

Year	Date	Time MST	Locality	Coordinates Deg. N. Lat.	Coordinates Deg. W. Long.	Intensity MM	Magnitude	Felt Area (sq mi)	Source	Zone
1975	30 Jun	1824*	Yellowstone N. P., Wyoming	44.79	110.54	—	M_L = 3.5			A
1975	30 Jun	1847*	Yellowstone N. P., Wyoming	44.80	110.54	--	M_b = 4.6			A
1975	30 Jun	1854*	Yellowstone N. P., Wyoming	44.75	110.61	VII	M_b = 5.6	50,000 km^2		A
1975	30 Jun	1901*	Yellowstone N. P., Wyoming	44.77	110.72	—	M_b = 5.1			A
1975	30 Jun	1917*	Yellowstone N. P., Wyoming	44.92	110.65	II	M_L = 4.2			A
1975	30 Jun	1956*	Yellowstone N. P., Wyoming	44.71	110.52	—	M_b = 4.7			A
1975	30 Jun	2020*	Yellowstone N. P., Wyoming	44.69	110.59	III	M_b = 4.9			A
1975	30 Jun	2046*	Montana	45.03	110.75	--	M_L = 3.4			A
1975	30 Jun	2115*	Montana	45.04	110.57	--	M_L = 3.1			A
1975	1 Jul	0416*	Yellowstone N. P., Wyoming	44.79	110.74	II	M_b = 4.8			A
1975	1 Jul	1557*	Yellowstone N. P., Wyoming	44.79	110.74	II	M_L = 3.4			A
1975	2 Jul	0829*	Yellowstone N. P., Wyoming	44.79	110.76	II	M_b = 4.6			A
1975	2 Jul	1954*	Yellowstone N. P., Wyoming	44.72	110.57	—	M_b = 4.2			A
1975	3 Jul	0321*	Yellowstone N. P., Wyoming	44.75	110.46	--	M_b = 4.5			A
1975	5 Jul	1917*	Yellowstone N. P., Wyoming	44.71	110.62	IV	M_b = 4.5			A
1975	5 Jul	2008*	Yellowstone N. P., Wyoming	44.76	110.64	III	M_b = 3.5			A

(Continued)

* Greenwich Mean Time.

Table B1 (Continued)

Year	Date	Time MST	Locality	Coordinates Deg. N. Lat.	Deg. W. Long.	Intensity MM	Magnitude	Felt Area (sq mi)	Source	Zone
1975	6 Jul	0512*	Yellowstone N. P., Wyoming	44.72	110.68	--	—			A
1975	7 Jul	0051*	Yellowstone N. P., Wyoming	44.76	110.57	II	$M_b = 4.3$			A
1975	11 Jul	0537*	Yellowstone N. P., Wyoming	44.71	110.74	--	$M_b = 3.7$			A
1975	13 Jul	1001*	Yellowstone N. P., Wyoming	44.71	110.67	IV	$M_b = 4.4$			A
1975	16 Aug	2120*	E. Idaho	42.12	112.45	--	M = 3.6			C
1975	17 Aug	1024*	Hebgen Lake, Mont.	44.67	111.11	--	—			A
1975	8 Sep	1156*	Hebgen Lake, Mont.	44.20	111.28		M = 2.5			A
1975	12 Sep	1826*	E. Idaho	42.07	112.57	III	M = 4.0			C
1975	12 Sep	1857*	E. Idaho	42.09	112.49					C
1975	14 Sep	0413*	N. Utah	41.87	112.43	III				C
1975	22 Sep	1042*	E. Idaho	42.08	112.45	IV	$M_b = 4.2$			C
1975	13 Oct	0659*	E. Idaho	42.00	112.56					C
1975	9 Nov	0855*	E. Idaho	41.99	112.52					C
1975	17 Nov	0821*	E. Idaho	41.96	112.53		M = 3.0			C
1975	5 Dec	1106*	Hebgen Lake, Mont.	44.42	111.44		M = 2.4			A
1975	20 Dec	0144*	E. Idaho	42.00	112.53		M = 2.7			C
1976	11 Feb	0328*	N. Utah	41.27	111.84	III	$M_L = 2.7$			—
1976	27 Feb	0718*	N. Utah	41.24	111.27	II	$M_L = 2.4$			—
1976	7 Jun	0448*	Yellowstone N. P., Wyoming			V				A
1976	7 Jun	1207*	Yellowstone N. P., Wyoming			V				A
1976	14 Jun	0937*	E. Idaho	42.12	112.48	IV	$M_L = 3.6$			C
1976	15 Jun	0208*	N. Utah	41.89	112.44	III	$M_L = 3.1$			C
1976	19 Oct	0618*	Yellowstone N. P., Wyoming	44.74	110.81	IV	$M_b = 5.3$			A

(Continued)

* Greenwich Mean Time.

Table B1 (Continued)

Year	Date	Time MST	Locality	Coordinates Deg. N. Lat.	Coordinates Deg. W. Long.	Intensity MM	Magnitude	Felt Area (sq mi)	Source	Zone
1976	19 Oct	0724*	Yellowstone N. P., Wyoming	44.80	110.70	IV	M_b= 5.3			A
1976	5 Nov	0115*	N. Utah	41.82	112.69	II	M_L= 3.4			C
1976	5 Nov	0248*	N. Utah	41.81	112.70	V	M_L= 4.1			C
1976	17 Nov	1434*	Yellowstone N. P., Wyoming	44.75	110.86	IV	M_L= 3.7			A
1976	17 Nov	1457*	Yellowstone N. P., Wyoming	44.74	110.83	II	M_L= 3.0			A
1976	27 Nov	0024*	Hebgen Lake, Mont.	44.64	111.14	IV	M_L= 3.7			A
1976	27 Nov	0109*	Yellowstone N. P., Wyoming	44.66	110.82	III	M_L= 3.5			A
1976		1918*	Yellowstone N. P., Wyoming	44.85	110.97	II	M_L= 3.6			A
1976	8 Dec	1440*	Yellowstone N. P., Wyoming	44.76	110.79	V	M_b= 5.5			A
1976	8 Dec	2210*	Hebgen Lake, Mont.	44.75	110.05	III	M_L= 3.5			A
1976	9 Dec	2236*	Yellowstone N. P., Wyoming	44.77	110.80	V	M_b= 4.5			A
1976	16 Dec	0028*	Yellowstone N. P., Wyoming	44.64	110.05	IV	M_L = 3.0			A
1976	19 Dec	1710*	Yellowstone N. P., Wyoming	44.77	110.80	VI	M_b= 4.9			A
1976	20 Dec	0134*	Yellowstone N. P., Wyoming	44.84	110.83	IV	M_b= 4.4			A
1976	20 Dec	1707*	Hebgen Lake, Mont.	44.50	111.07	III	M_L= 3.3			A
1977	4 Mar	1005*	Hebgen Lake, Mont.	44.83	111.04		M_b= 3.9			A
1977	4 Mar	1101	Hebgen Lake, Mont.	44.79	111.08		M_b= 3.9			A
1977	4 Mar	1300	Hebgen Lake, Mont.	44.80	111.08	IV	M_b= 4.1			A

* Greenwich Mean Time.

(Continued)

Table B1 (Concluded)

Year	Date	Time MST	Locality	Coordinates Deg. N. Lat.	Coordinates Deg. W. Long.	Intensity MM	Magnitude	Felt Area (sq mi)	Source	Zone
1977	4 Mar	1304	Hebgen Lake, Mont.	44.82	111.10		M_b = 4.0			A
1977	4 Mar	1419	Hebgen Lake, Mont.	44.78	111.05		M_b = 4.0			A
1977	4 Mar	1439	Hebgen Lake, Mont.	44.84	110.92		M_L = 3.8			A
1977	4 Mar	1500	Hebgen Lake, Mont.	44.82	111.05		M_L = 3.8			A
1977	4 Mar	1651	Hebgen Lake, Mont.	44.77	111.21		M_L = 4.0			A
1977	4 Mar	1710	Hebgen Lake, Mont.	44.76	111.01		M_b = 4.0			A
1977	11 Mar	1217	Hebgen Lake, Mont.	44.85	111.5		M_b = 5.2			A
1977	2 Apr	2303	Hebgen Lake, Mont.	44.75	110.82		M_L = 3.9			A
1977	19 Oct	1650	Hebgen Lake, Mont.	44.77	111.81		M_L = 4.7			A